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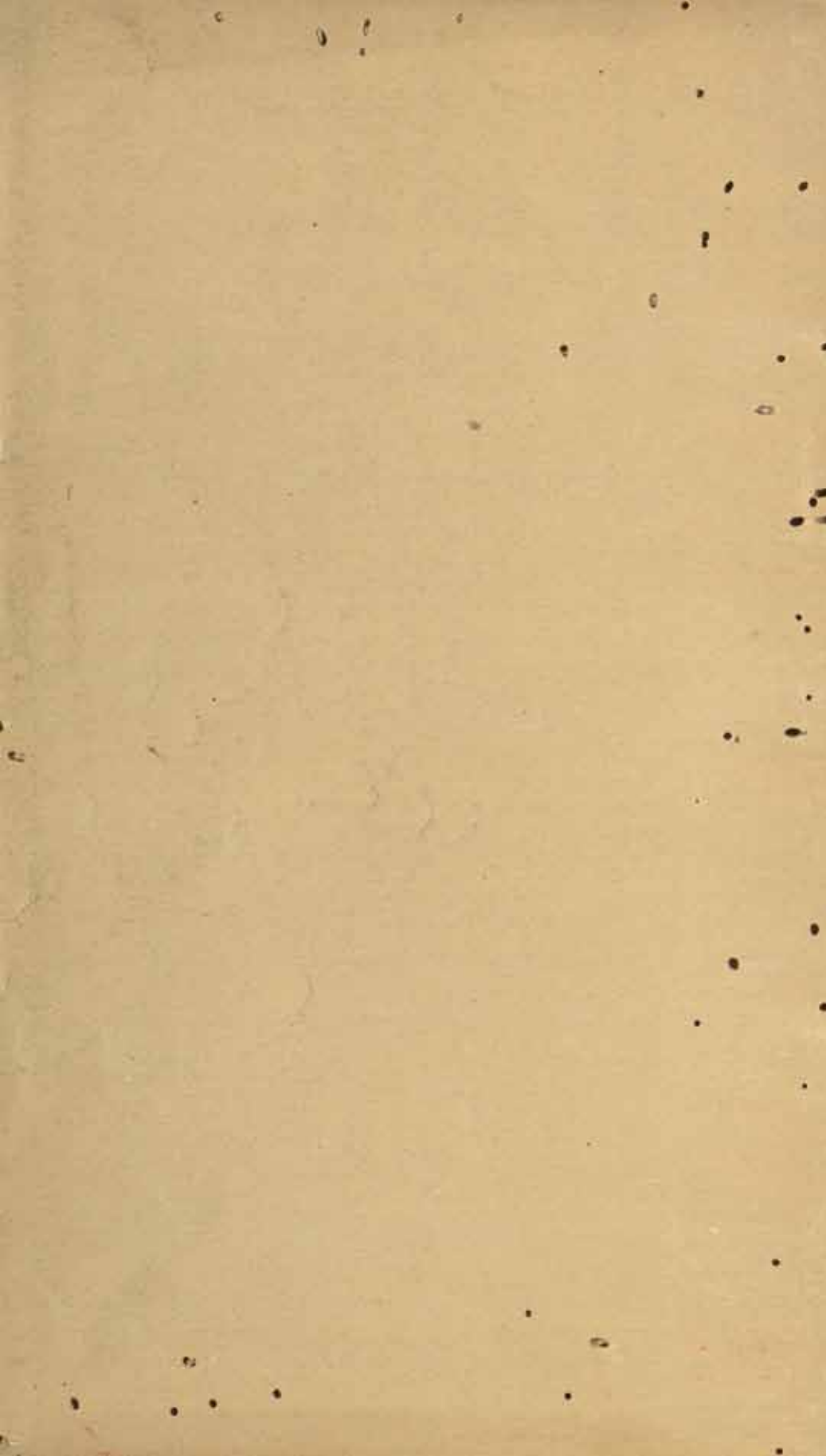
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GRAY'S ANATOMY

Descriptive and Applied

THIRTY-SECOND EDITION

EDITED BY

T. B. JOHNSTON

C.B.E., M.D.

Professor Emeritus of Anatomy

University of London

D. V. DAVIES

M.A.(Cantab.), M.B., B.S.

Professor of Anatomy

St. Thomas's Hospital Medical School

University of London

F. DAVIES

M.D., D.Sc.(Lond.), F.R.C.S.

Professor of Anatomy

University of Sheffield

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University of Sheffield. |

PREFACE
TO
THE THIRTY-SECOND EDITION

THE untimely death of Professor James Whillis early in 1955 has led to the formation of an Editorial Board. Professor Francis Davies, of the University of Sheffield, who has for many years undertaken the revision of the Digestive and Respiratory Systems, has joined the Board and for this Edition he has also undertaken the task of revising and in many parts rewriting the Autonomic Nervous System, the Organs of the Senses, the Urogenital System and the Ductless Glands. In addition it has proved desirable to give further help to the Senior Editor, and Professor D. V. Davies of St. Thomas's Hospital has been added to the Board. He has been responsible for the revision and complete rewriting of many parts of the sections dealing with Histology, Embryology, the Joints, the Muscles and the Central Nervous System. The Senior Editor has revised the sections dealing with Osteology, Angiology and the Peripheral Nervous System, and has included new matter in connexion with the Anatomy of the Heart. The Editorial Board is indebted to Mr. R. F. H. Brain, M.S., F.R.C.S., Assistant Surgeon in the Department of Thoracic Surgery, Guy's Hospital, for revising and rewriting most of the paragraphs dealing with Surgical Applied Anatomy.

The late Professor James Whillis had been connected with *Gray's Anatomy* for many years, for he had assisted the late Professor Howden in a minor capacity, and the Senior Editor in a major capacity, before he became a Joint Editor in 1940. His loss is greatly deplored by all who have the well-being of *Gray's Anatomy* at heart.

A happy coincidence has brought Professor D. V. Davies into touch with Miss A. S. Fitton Jackson, for to her the Editorial Board is deeply indebted for the loan of the electron micrographs which appear in the sections of Histology and Embryology. It is especially fortunate that we are able to include these beautiful photographs in the Centenary Edition, for Miss Fitton Jackson is a blood relative of Henry Gray himself.

We are acutely conscious of the importance of maintaining the high standards previously attained by the illustrations, and again we have been fortunate in having the services of Mr. S. W. Woods, whose figures are always accurate, clear and beautifully finished. This edition contains more than a hundred new figures, many of which were required to replace old blocks that had been badly worn. We acknowledge gratefully our debt to Mr. Woods for his meticulously careful work.

As always in the past we have received much generous help from friends and colleagues, too numerous to mention individually, but we wish to thank especially Mr. R. J. Scothorne, Lecturer in Human Anatomy, University of Glasgow, Mr. W. Hewitt, St. Thomas's Hospital Medical School and Mr. R. Sprinz, University of Sheffield. We desire to thank also those readers, both at home and abroad, who have taken the trouble to draw our attention to typographical and other minor errors. Their help is very greatly appreciated.

The index is the work of Dr. P. L. Williams, of the Anatomy Department,

Guy's Hospital, and he has devoted much care and discrimination to this rather thankless and tedious task.

Since 1933 the Editors have used the B.R. Terminology (Birmingham Revision of the B.N.A.) in *Gray's Anatomy*, but at Oxford in 1950 the Fifth International Congress of Anatomists set up an International Anatomical Nomenclature Committee to review Anatomical Nomenclature. The Report of this Committee was accepted (*nem. con.*) by the Sixth International Congress of Anatomists at Paris in 1955 and, further, a recommendation to set up a Standing Nomenclature Committee to deal with any pertinent matters as they may arise was unanimously adopted.

The Editorial Board of *Gray's Anatomy* gave full consideration to the action that should be taken in this connexion and it was unanimously agreed to insert the *Nomina Anatomica* Paris in the Centenary Edition, taking full advantage of their freedom to translate the Latin forma into its English equivalent. It was further decided to be very sparing in the use of parentheses and to avoid their constant repetition. Accordingly, where the N.A.P. term differs from the B.R. term, the latter is included in parenthesis on the first and often on the second occasion that the same structure is mentioned, but thereafter the N.A.P. term is used without any parenthesis. The Editors sincerely hope that the line of action they have adopted will be accepted as a reasonable step to take and one which, in the general interests, is fully justifiable. It will be found on reading that the I.A.N.C. adopted a highly conservative attitude in their revision of the B.N.A.

T. B. J.
D. V. D.
F. D.

ONE HUNDRED YEARS OF GRAY'S ANATOMY

THE present edition is published one hundred years after the first edition, and so constitutes the Centenary Edition of the work. It should therefore be of interest to summarize the main features of its history.

Henry Gray died soon after the publication of the second edition, when he was only 34, but he had already, at the very early age of 25, been elected a Fellow of the Royal Society. His work on the "Development in man of the Retina and the Optic Nerve and of the Membranous Labyrinth and the Auditory Nerve" had marked him out as a man of great ability and originality and had very favourably impressed Sir Benjamin Brodie, F.R.S., who was then the Senior Surgeon at St. George's Hospital and to whom the first edition of *Gray's Anatomy* was dedicated. Gray was a man of unusual industry and his first edition ran to 750 pages and contained 363 figures, all drawn by his friend Dr. H. Vandyke Carter, most of them from fresh dissections, which were the work of Gray and himself.

The book had a somewhat mixed reception from its reviewers. The *Lancet* gave it a very favourable notice, but the *Medical Times* appears to have been very critical and even suggested, quite unjustifiably, that it owed much to the then current edition of Quain and Sharpey's *Anatomy*. Nevertheless the book appealed strongly to medical students, for whom Gray specially intended it, and was sold out inside two years. The second edition showed little change from the first, a fact that may well be explained by the urgency for its publication.

The first two editions were published by John W. Parker & Son, London, who sold the rights for the United States of America to the New York firm of Lee and Blanchard, later Lee and Febiger. Soon after Gray's death Longmans, Green & Co. bought the rights for Great Britain and the rest of the world from Parker and Son, who were giving up business. By private arrangement the earlier American editions were facsimiles of the English edition but, not long after the turn of the century, Lee and Febiger appointed their own editor, with the result that the English edition now contains much matter which differentiates the two. Despite heavy losses caused by enemy action during the war, one of the correspondence files still preserved contains a copy of Gray's original contract with Parker & Son and letters that passed between them. It is specially interesting to note that Gray expresses the hope that he is not "being too sanguine" in anticipating that there will be need for a second and, possibly, further editions.

Longmans invited Timothy Holmes, M.A., F.R.C.S., Assistant Surgeon to St. George's Hospital, to edit the third and seven succeeding editions. He was a man with a great reputation as a teacher at St. George's Hospital and had been in close touch with Gray during the preparation of the second edition. They had discussed the desirability of adding sections on Histology and Embryology, but

Gray felt that they should be added later. Consequently it fell to Holmes to introduce these two sections in the third edition and, for many years, under the title of General Anatomy they constituted the first 145 pages, numbered in Roman figures, and were followed by the Osteology section which commenced on page 1.

Holmes held that "Vital phenomena are purely within the domain of the Physiologist" and it took time for Anatomists to appreciate that there must be, or ought to be, considerable overlapping between the two subjects, if only because the Physiologist, while devoting his attention to living muscle and its problems, had never concerned himself with the individual muscles and joints of the body. As a result, apart from increased space given to Histology and Embryology, the book showed little tendency to expansion for many years.

The third editor was also Surgeon to St. George's Hospital, T. Pickering Pick, F.R.C.S., and, after helping Holmes to revise the ninth edition, he took complete responsibility for the tenth and four subsequent editions. One of the first changes he introduced was to incorporate the Histology and Embryology into the text proper. The brief summaries of the structure of most of the organs, which Gray had included in the appropriate section, were incorporated so that the book remained substantially the same size and its contents were at first retained very much as they had been written originally.

In the eleventh edition, in 1887, colour was introduced for the first time, restricted to the vessels and nerves, and had the effect of making the book more attractive in appearance.

When the fifteenth edition was being prepared for publication, the late Professor R. Howden, M.A., M.B., C.M., D.Sc., LL.D., Professor of Anatomy at Durham University, was brought in to assist Pickering Pick and in 1909 he took over full responsibility for the book for the seven succeeding editions. During this period he revised and partially rewrote many of the sections, expanding them considerably and adding a large number of new figures, so that when he came to resign the editorship in 1928 the book had more than 1300 pages and nearly as many figures. A new section, dealing with Surface Anatomy and Surface Marking, was introduced on account of the increased amount of attention being given to Living Anatomy. At a later date this section was omitted because it was found more desirable to correlate the information it contained more closely with the descriptions of the individual structures concerned.

In the last thirty years, under the present Editorship, the emphasis given to Living Anatomy has steadily increased and the purely morphological aspects of the subject have been as steadily diminished. Further, the introduction of a representative series of X-ray photographs has, it is hoped, retained the emphasis which Gray originally laid on the necessity for a Textbook of Human Anatomy to provide the medical student with the kind of information he most needed.

The sections dealing with Embryology and the Central Nervous System have been considerably expanded by the inclusion of much new matter. The figures and plates now total 1329 and the text alone now comprises 1546 pages.

Originally *Gray's Anatomy* was written in the terminology current at the time of its publication, but when the Basle *Nomina Anatomica*, which was the first essay at an official terminology, was first published in 1895, Professor Howden soon adopted it. Forty years later British Anatomists were no longer satisfied with the

B.N.A. and they had issued a revised version known as the B.R. (Birmingham Revision) which in its turn has given way to the N.A.P. (Nomina Anatomica, Paris). These changes can be correlated with the enormous advances made in anatomical knowledge, favoured by the subsidies forthcoming for research work made in many countries, and the establishment of a standing Anatomical Nomenclature Committee by the International Congress of Anatomists at their meeting in Paris in 1955 should make it a much simpler process to effect such changes as may in future prove necessary.

T. B. JOHNSTON



VIEW OF THE DISSECTING ROOM OF ST. GEORGE'S
HOSPITAL, 27 MARCH 1860

Henry Gray is seated second from the left in the front row.



Timothy Holmes 1863-1880



T. Pickering Pick 1883-1905



Henry Gray 1858-1860



R. Howden 1909-1926



J. Whillis 1942-1954

PAST EDITORS OF GRAY'S ANATOMY

NOMINA ANATOMICA PARIS

THE number of new terms introduced by the N.A.P. is relatively small, for it was based on the B.N.A., and in very many instances the terms, though differing from the B.N.A., are identical with the terms used in the B.R., which has been current in English Anatomical textbooks since its introduction in 1933. Further, in a large percentage of cases the changes themselves are of minor degree and, on that account, the Editors do not propose to include a complete glossary. On the other hand they believe that the subjoined list, which contains all the more radical alterations, will serve as a useful reminder for readers who may already have started their courses in Human Anatomy as well as for others who have already become accustomed to the B.R.

N.A.P.

B.R.

Dens (axis)	Processus odontoideus
Incisura jugularis	Incisura suprasternalis
Tuba auditiva	Tuba pharyngotympanica
Canalis opticus	Foramen opticum
Incisura scapulae	Incisura suprascapularis
Tubercula (humeri)	Tuberositates (humeri)
Sulcus n. radialis	Sulcus spiralis
Condylus humeri	<i>Not named in B.R.</i>
Facies lunata acetabuli	Facies articularis acetabuli
Linea glutea anterior (ilii).	Linea glutea media
Apex (capitis fibulae)	Processus styloideus fibulae
Menisci	Cartilagine semilunares
Ventralis et Dorsalis (<i>often used</i>)	Anterior et Posterior
Musculus erector spinae	Musculus sacrospinalis
Galea aponeurotica	Aponeurosis epicranialis
Lig. lacunare	Lig. inguinale (pars pectinealis)
M. flex. dig. superficialis	M. flex. dig. sublimis
Sulcus coronarius	Sulcus atrioventricularis
Septum atrioventriculare	<i>Not named in B.R.</i>
Myocardium	Neuromyocardium
Valva a.v. dextra [V. tricuspidalis]	Valvula a.v. dextra [Valvula tricuspidalis]
Crista supraventricularis	Crista infundibulo-ventricularis
Conus arteriosus	Infundibulum
Valva trunci pulmonalis	Valvula trunci pulmonalis
Trabecula septomarginalis	Fasciculus moderator
Valva aortae	Valvula aortae
Valvulae	Cuspides
Sinus trunci pulmonalis	<i>Not named in B.R.</i>
Rami pulmonales segmentorum pulmonalium	<i>Not named in B.R.</i>

N.A.P.

B.R.

Truncus brachiocephalicus

A. labyrinthi

A. thoracica interna

A. thoraco-acromialis

A. thoracodorsalis

Aa. sigmoideae

Vv. brachiocephalicae

V. vertebralis accessoria

V. retromandibularis

{ V. facialis

{ "

Nodus lymphaticus [Lymphonodus]

Medulla spinalis

Nucleus dorsalis

Tractus corticospinales

" corticopontini

Lamina tecti

Colliculus superior

" inferior

Adhaesio interthalamica

Gyrus parahippocampalis

*Radiatio acustica

Ganglion pterygopalatinum

N. stato-acusticus [N. octavus]

Truncus vagalis anterior

Truncus vagalis posterior

Ansa cervicalis

N. thoracodorsalis

N. dorsalis scapulae

N. axillaris

N. peroneus communis

N. peroneus superficialis

N. peroneus profundus

N. tibialis

N. tibialis

N. rectalis inferior

Isthmus faucium

Tendo crico-oesophageus

A. innominata

A. auditoria interna

A. mammaria interna

A. acromio-thoracalis

Not named in B.R.

Aa. colicae sinistrae inferiores

Vv. innominae

Not named in B.R.

V. facialis posterior

V. facialis anterior

V. facialis communis

Lymphoglandula

Chorda spinalis

Nucleus thoracalis

Fibrae cerebrospinales

Fibrae cerebropontinae

Tectum

Corpora quadrigemina superiora

Corpora quadrigemina inferiora

Connexus interthalamicus

Gyrus hippocampalis

Radiatio auditoria

Ganglion sphenopalatinum

N. auditorius

Not named in B.R.

Not named in B.R.

Ansa hypoglossi

N. m. latissimus dorsi

N. mm. rhomboideorum

N. circumflexus

N. popliteus lateralis

N. musculocutaneus

N. tibialis anterior

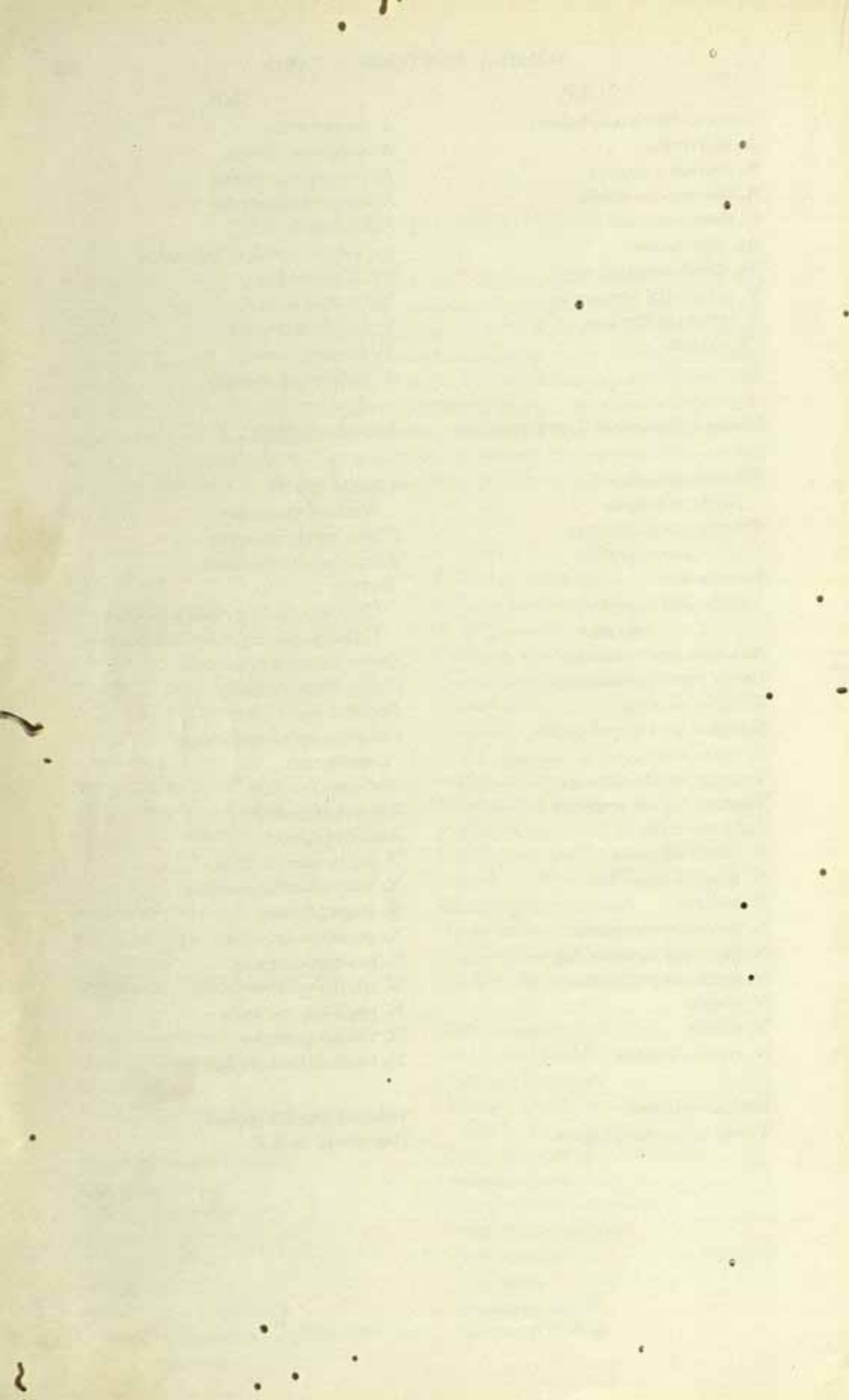
N. popliteus medialis

N. tibialis posterior

N. haemorrhoidalis inferior

Isthmus oropharyngeus

Not named in B.R.



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HUMAN ANATOMY

INTRODUCTION

THE term *human anatomy* comprises a consideration of the various structures which make up the human body. In a restricted sense it deals merely with the parts which form the fully developed individual, and can be demonstrated to the naked eye by various methods of dissection. Regarded from that standpoint, human anatomy may be studied by two methods: (1) the various structures may be considered as individual entities—*systematic anatomy*; or (2) the organs and tissues may be studied as they lie in relationship with one another in the different regions of the body—*topographical* or *regional anatomy*. The practical value of the knowledge acquired through dissection of the cadaver by either line of study can be greatly enhanced by frequent reference to the living body and the identification of those structures which are susceptible of examination through the skin. This aspect of the subject is termed *surface anatomy*. Additional information on the structure of the living body can be obtained with the aid of radiography and, on account of the steady improvement of radiographical technique, the scope of *radiological anatomy* is constantly increasing. Both surface examination and radiography of the living body are of general application, both in health and disease, and are in daily use in medical practice. In addition certain individual organs can be inspected with the aid of instruments specially devised for the purpose, and the text contains many references to these methods of examination.

It is, however, essential to supplement the facts ascertained by naked-eye dissection by those observed by means of the microscope. In this way two fields of investigation are opened, viz. the study of the minute structure of the various component parts of the body—*histology*; and the study of the human organism in its immature condition, from the fertilisation of the ovum to the birth of the child—*embryology*. The importance of the various tissues and organs depends on the functions which they subserve and a very intimate relationship always exists between structure and function.

The changes through which any organism passes from the fertilisation of the ovum until the fully adult form is reached constitute its *ontogenetic history* or *ontogeny*. *Phylogeny*, on the other hand, comprises the evolutionary history of the group to which the organism belongs. Owing to the difficulty of interpreting many of the features of human development, recourse must be had to observations on the development of lower but allied forms—*comparative embryology*.

In its broader conception anatomy deals with the factors which have influenced and determined the form, structure and functions of the constituent parts of the body, and this aspect of the subject is termed *morphology*. In this branch much valuable information is obtained from the study of the anatomy of other animals, or *comparative anatomy*.

The direct application of the facts of human anatomy to medicine and surgery constitutes the subject of *applied anatomy*.

In the earlier stages of the development of all vertebrates there are abundant signs of their evolution from a segmented invertebrate type. In their simplest forms the segments are identical with one another, save for their topographical

position, and the individual structures contained in each segment are repeated in the other segments. The segments are said to be *serially homologous* with one another, and identical individual structures, repeated from segment to segment, provide further examples of *serial homology*.

When two structures occurring in different animals have similar ontogenetic histories, even though they may show individual differences in other ways, they are said to be *homologous* with each other. Thus, the wing of a bird, the fore-limb of a horse and the upper limb of a man are homologous structures, for, although they differ widely in their structure and functions, they all develop from identical cell-groups in the embryo. Structures which fulfil the same functions in different animals are not necessarily homologous with one another. The gills, which constitute the respiratory apparatus of the fish, are not homologous with the lungs, which carry out a precisely similar function in man, because they have different ontogenetic histories. Such organs are said to be *analogous*.

SYSTEMATIC ANATOMY.—The various tissues of which the body is composed are built up in different combinations and in varying proportions into organs and structures, which can be arranged in a number of groups or *systems*, according to the functions which they perform.

1. *Osteology*—the bony system or skeleton.
2. *Syndesmology*—the articulatory system or joints.
3. *Myology*—the muscular system.

It may be noted that the bony, articulatory and muscular systems, grouped together, constitute the *locomotor apparatus*.

4. *The Blood Vascular System*—comprising the heart, blood-vessels, lymph vessels and lymph nodes.

5. *Neurology*—the nervous system. It is convenient to include the organs of the senses in this system.

6. *Splanchnology*—the visceral system. The heart, a thoracic viscus, is included in the blood vascular system, and the remaining viscera are grouped into: (a) the *respiratory system*; (b) the *digestive system*; and (c) the *urogenital system*.

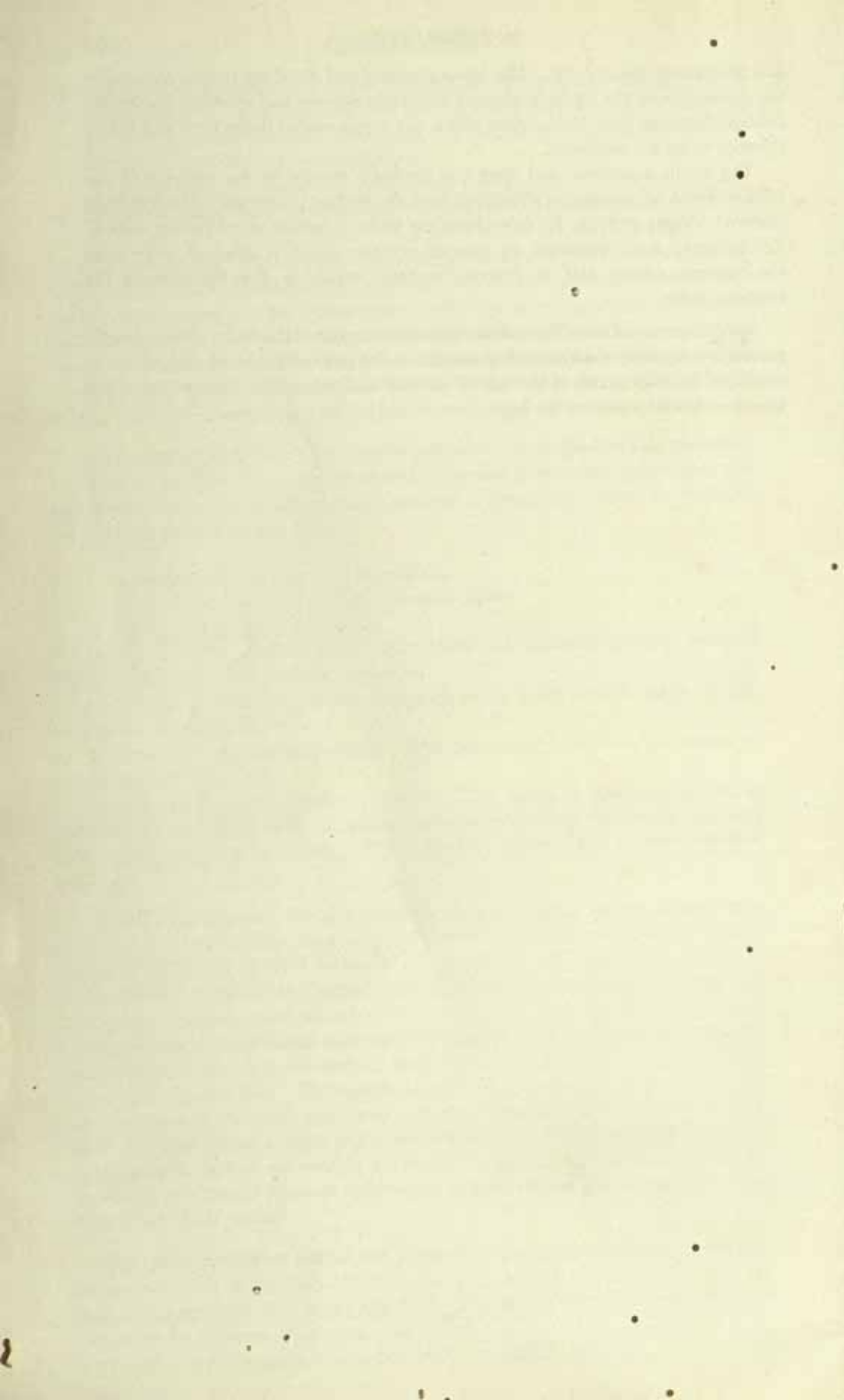
DESCRIPTIVE TERMS.—For descriptive purposes the body is always assumed to be in the *erect posture*, with the arms hanging by the side, and the head, the eyes and the palms of the hands directed forwards. The position is an unnatural one, for it entails lateral rotation of the humeri at the shoulder joints. The *median plane* is a vertical plane which passes through the centre of the trunk and divides the body into superficially symmetrical right and left halves. This plane cuts the anterior surface of the body along the *anterior median line*, and the posterior surface, along the *posterior median line*. The median plane will pass approximately through the sagittal suture of the skull, and hence any plane parallel to it is termed a *sagittal plane*. Vertical planes at right angles to the median plane pass through or parallel to the central part of the coronal suture of the skull; such planes are termed *coronal planes*. Planes drawn at right angles to both sagittal and coronal planes are termed *horizontal planes*.

The terms *anterior* or *ventral* and *posterior* or *dorsal* are employed to describe the front or back of the body or limbs, and the relations of structures within the body to one another. The terms *superior* and *inferior* are used to indicate the relative levels of different structures, but in the study of embryology it is more convenient to use the terms *cranial* and *caudal* to denote relationships to the head

and tail ends of the embryo. The terms *proximal* and *distal* are frequently used in the description of the limbs in place of the terms *superior* and *inferior*. To denote relative distances from the median plane, the terms *medial* (nearer to) and *lateral* (further from) are employed.

The terms *superficial* and *deep* are confined strictly to descriptions of the relative depth of the various structures from the surface; *external* and *internal* are reserved, almost entirely, for describing the walls of cavities or of hollow viscera. For example, a rib possesses an external surface, which is directed away from the thoracic cavity, and an internal surface, which is directed towards the thoracic cavity.

Special terms are restricted for use to certain regions of the body. For example, *palmar* is frequently used instead of *anterior* in the palm of the hand, and *plantar* is employed in descriptions of the sole of the foot and *peroneal* in descriptions of the lateral or fibular aspect of the leg.

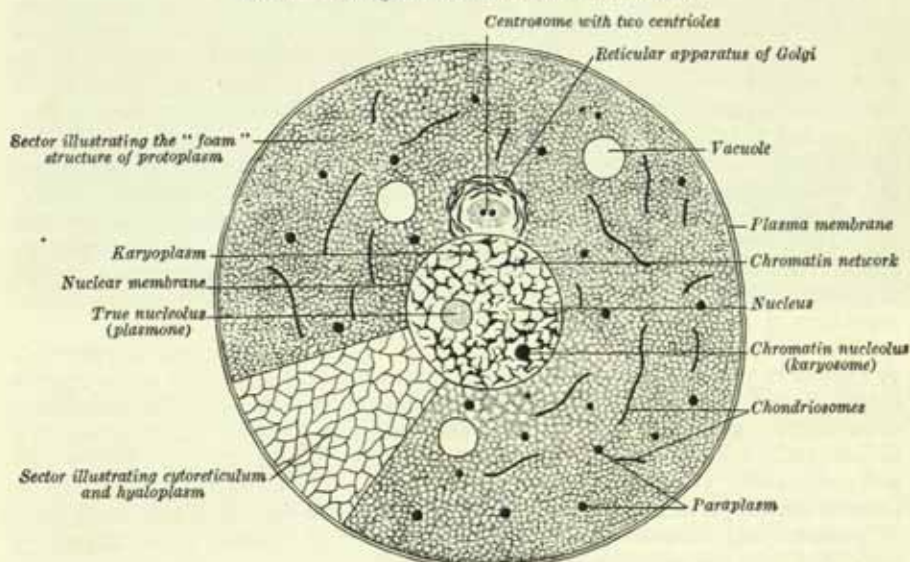


HISTOLOGY

THE ANIMAL CELL (fig. 1)

ALL the tissues and organs of the body originate from the germ-cell (*ovum*) of the female after it has been fertilised by the germ-cell (*spermatozoön*) of the male. The fertilised ovum divides and subdivides into an enormous number of cells which become variously modified in size, shape and other characteristics according to their positions and functions. All, however, consist of a viscid, unstable, semifluid substance named *protoplasm*. This is a highly complex material of colloidal nature, consisting of water, which forms from 70 per cent to 80 per cent of its total weight, proteins, carbohydrates, fats and inorganic and organic salts. It contains a variety of enzyme systems which catalyse the activities of the cell and its precise chemical composition is in a constant state of flux. When a living cell, healthy and

FIG. 1.—A diagram of a cell. (After fixation.)



unspecialised, is examined under the high powers of the conventional microscope the protoplasm of the cell body (*cytoplasm*) consists of an apparently homogeneous substance in which are embedded various granules and vacuoles and a more highly refractile usually globular mass, the *nucleus*. A cell is therefore frequently defined as "a mass of protoplasm containing a nucleus" but this definition is not altogether satisfactory, because some cells (e.g., red blood cells of mammals) are non-nucleated, and may carry on their functions for a limited time, while others (e.g., some cells in red bone marrow) may be multinucleated.

The **cytoplasm** varies in its appearance when fixed with chemical reagents according to the method of preparation, physiological state of the cell and other factors. Under some circumstances it may be homogeneous, fibrillar, granular, foamy or alveolar in nature. These appearances have in the past led to two main views concerning the structure of cytoplasm: (a) that it consists of a *cytotreticulum*, the meshes of which are filled with a clear, more fluid material, the *hyaloplast*, and (b) that it has an alveolar foam-like structure with a more viscid interalveolar substance (fig. 1). These views, based on fixed material have not been confirmed by the examination of normal living cells.

Whilst many of the appearances in fixed preparations are artifacts, similar cells under comparable conditions reproduce their own characteristic "fixation image" which is indicative of some pre-existing organisation in the cytoplasm.

Most cells are surrounded by a thin wall, the *cell membrane* or *plasma-membrane*, differentiated from the outer part of the cytoplasm or ectoplasm of the cell. This membrane is resilient and elastic and measures from 100 Å to 200 Å in thickness* (fig. 2). It maintains the individuality of the cell and plays an important role in the exchanges which occur between the cell and its environment. Some authorities attribute a sieve-like structure to the plasma-membrane, whilst others believe it to consist of a semipermeable lipid layer with a layer of protein molecules absorbed on each of its surfaces. With the electron microscope the plasma-membrane is frequently seen to consist of two parallel lamellae separated by a clear space (fig. 2). Some cell membranes, however, are known not to be primarily lipid in nature.†

In addition to the nucleus the cytoplasm contains several differentiated inclusions which are regarded as the *organelles* of the cell. These‡ include the centrosome, mitochondria and Golgi apparatus.

The **centrosome** is present in most cells. It lies near the nucleus and has the appearance of a small spherical mass of clear protoplasm. One or two minute particles, named *centrioles*, are found within it and play an important part in cell division. They are also related to the formation and anchorage of the cilia and flagellae which are present on some cells. Centrioles are said to be absent from cells which are incapable of further division.

The **mitochondria** occur in all cells and can be distinguished in both living and fixed preparations. They consist of minute granules, rods or filaments and are soluble in ether and dilute osmic acid. In suitably fixed preparations they can be stained by iron haematoxylin and other dyes and are darkened by osmic acid. In living cells they are readily stained by Janus Green B. Electron microscopy shows the individual mitochondria to be bounded by a membrane which is frequently double, and to possess an internal system of more or less regularly spaced ridges or double lamellae, the *cristae mitochondriales* (fig. 2). Between the lamellae is a homogeneous substance, slightly denser than the cytoplasm, the *mitochondrial matrix*.§ Mitochondria can be separated from the remainder of the cytoplasm by differential centrifugation.¶ They consist largely of lipo-protein and carry important enzymes concerned with cell respiration. They are regarded as important centres of oxidation activity in the cell and are believed by some authorities to have a role in the regulation of osmotic changes within the cell.

The **Golgi apparatus** || appears, under the ordinary microscope, as a network or a group of granules or rods in the neighbourhood of the nucleus or of the centrosome. Its nature and identity have been subject to much controversy but differential centrifugation and phase-contrast microscopy support the view that it occurs as a definite entity within the cell. Some of its components ¶ stain readily with silver salts and osmic acid. With the electron microscope the Golgi apparatus is revealed as a series of lamellae arranged in the form of a horseshoe and associated with a collection of granules and vacuoles (fig. 2). The apparatus is believed to be intimately associated with the secretory activities of the cell.

Electron microscopy has also revealed other submicroscopic structures in the cytoplasm. Amongst these are granules, vacuoles and numerous paired parallel lamellae (fig. 2). The latter are believed by some to be identical with the basiphilic component in the cytoplasm and to consist of nucleoprotein, the prosthetic group of which is ribonucleic acid ** †† whilst others identify them with the submicroscopic particles obtained by differential centrifugation of cell homogenates and termed *microsomes*.

Granules of fat, pigment, glycogen and other inclusions may also be embedded in the cell cytoplasm and are collectively spoken of as *paraplasms*; vacuoles may also be present.

The **nucleus** is generally spherical or globular and situated eccentrically within the cell. It is enclosed in a tough and slightly elastic nuclear membrane about

* 10,000 Å = 1 μ . 1,000 μ = 1 millimetre.

† For details and a history of Cytology, see G. R. Cameron, *Pathology of the Cell* Part I, Edinburgh, 1951.

‡ G. E. Paladi, *Anat. Rec.*, **114**, 1952.

§ R. R. Bensley and N. L. Hoerr, *Anat. Rec.*, **60**, 1934.

¶ For details, see "The Symposium on the Golgi apparatus", *J. Roy. Micr. Soc.*, **74**, 1954.

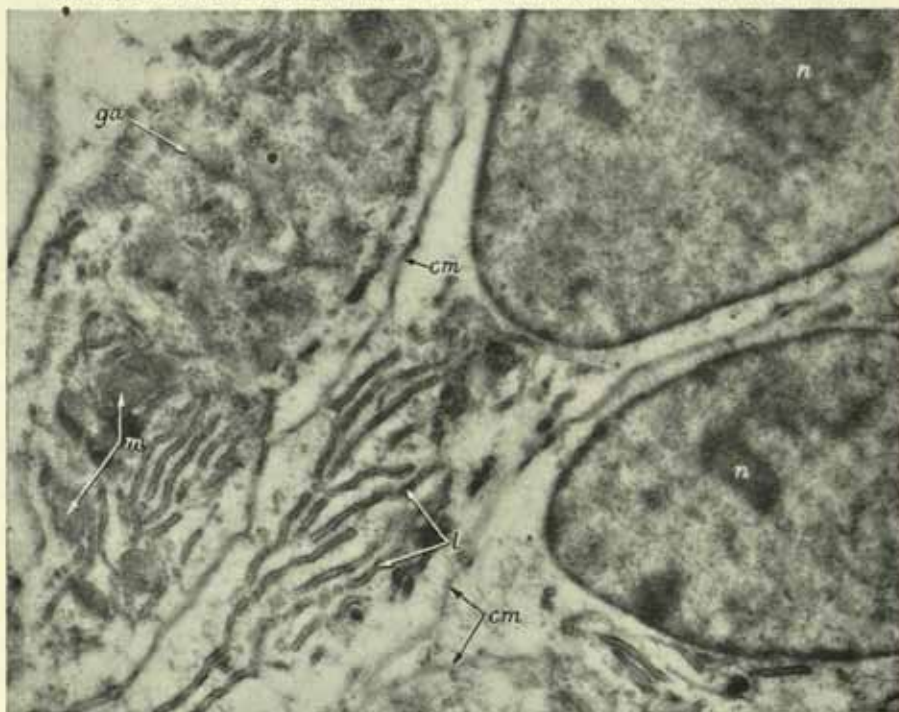
** K. C. Richardson, *Arch. Exp. Zellforsch.*, **16**, 1934.

†† T. Caspersen and J. Schultz, *Nature*, **143**, 1939.

‡‡ J. Brachet, *Compt. Rend. Soc. Biol.*, (Paris), **133**, 1940.

400 Å thick and often appearing double with the electron microscope (fig. 2). Within the nucleus is the *chromatin*, which has a strong affinity for basic dyes and is arranged in the form of a network or in discontinuous masses in fixed and stained

FIG. 2.—Electron micrograph of sections of cells from perichondrium. $\times 20,000$. Lent by Miss S. Fitton Jackson and reproduced by permission of the Royal Society.



n = nuclei : *cm* = cell membrane : *l* = cytoplasmic lamellae : *m* = mitochondria :
ga = Golgi apparatus.

preparations. The chromatin consists mainly of nucleoprotein, the nucleic acid component of which is deoxyribonucleic acid. This can be demonstrated histochemically by the Feulgen reaction and with methyl green, which is believed to be a specific stain for this nucleic acid. During cell division the chromatin is arranged along discrete filamentous bodies, known as the *chromosomes*. Though the chromosomes retain their identity during the interphase, it is not possible to demonstrate them at this stage of the life cycle of the cell. The reasons for this are not understood. The clear medium in which the chromatin is embedded is the *karyoplasm* or *nuclear sap*. In the female, however, most of the cells in the interphase or resting stage (p. 4) can be distinguished by the presence in the nucleus of a planoconvex mass of chromatin termed the *sex chromatin*. This is about 1μ in diameter and is generally, but not invariably, placed close to the inner surface of the nuclear membrane and is believed to consist of the still visible portion of the chromatin (heterochromatin) of the female sex chromosomes. A similar mass is also believed to be present in the nucleus of the cells of the male, but it is too small to demonstrate by ordinary light microscopy.* Within the nucleus and believed to be associated with specific chromosomes are one or more highly refractile bodies, *nucleoli*, which stain readily with acid dyes. They are believed to consist of phosphoprotein together with a small amount of ribonucleic acid.

Reproduction of cells is effected either by direct or by indirect division.

In *direct division* (*amitosis*) the nucleus becomes constricted in the middle, assuming an hour-glass shape, and then divides into two. This is followed by a cleavage or division of the whole protoplasmic mass of the cell; and thus two daughter cells are formed, each containing a nucleus. The daughter cells are at first smaller than the original mother cell; but they grow, and the process may be

* M. L. Barr and E. G. Bertram, *Nature*, **163**, 1949; M. L. Barr and E. G. Bertram, *J. Anat., Lond.*, **85**, 1951; and H. B. Lindsay and M. L. Barr, *ibid.* **89**, 1955.

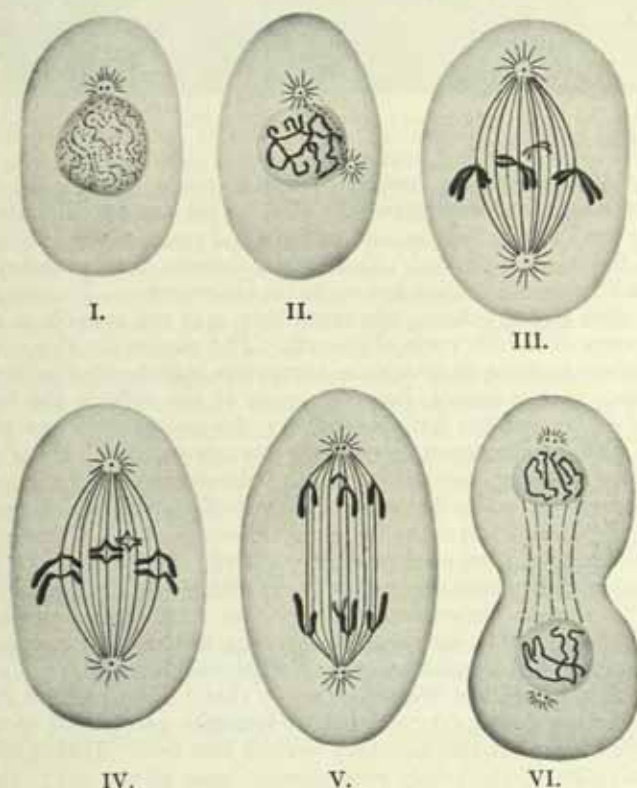
repeated in them, so that multiplication may take place rapidly. Direct division is said to occur in leucocytes and bone-cells, and in the epithelial cells lining the urinary bladder.

Indirect division or karyokinesis (mitosis) is the common method of division in the higher animals, and the process is characterised by a series of complex changes in the nucleus, leading to its subdivision; this is followed by cleavage of the cell-protoplasm. The whole process extends over a period of from thirty minutes to two or three hours. Starting with the nucleus in the quiescent or *resting* condition, these changes may be grouped briefly under the four following stages (fig. 3):

1. *Prophase*.—The nucleolus disappears and the chromosomes become apparent. Each chromosome consists of two chromatids or daughter chromosomes lying side by side. The number of chromosomes varies widely in different animals but is constant for all the somatic cells in animals of any given species. In man the number is forty-eight, of which half are maternal in origin, and half paternal.* Coincident with, or preceding, the definition of the chromosomes, the centrosome divides and the two resulting centrosomes move away from each other—one towards either extremity of the nucleus. As they separate, they are seen to be connected by a spindle of delicate achromatic fibrils, termed the *achromatic spindle*, which elongates proportionately to the separation of the centrosomes. At the end of the prophase (sometimes termed the *prometaphase*) the nuclear membrane disappears and the spindle sinks inwards so that its axis lies on a line joining the two centrosomes. The karyoplasm contributes additional peripheral fibres to the spindle. An imaginary line enclosing the spindle midway between its extremities, or *poles*, is named the *equator*.

2. *Metaphase*.—The chromosomes, which have become shorter and irregularly V-shaped, arrange themselves around the equator, each with the apex of the V

FIG. 3.—A diagram showing the changes which occur in the centrosome and nucleus of a cell in the process of mitotic division.



I and II, Prophase; III, Metaphase; IV and V, Anaphase; VI, Telophase.

* Recent investigations (J. H. Tjio and A. Levan, *Hereditas*, 42, 1956; C. E. Ford and J. L. Hamerton, *Nature*, 178, 1956) suggest that the correct number, including the x- and y-chromosomes (p. 65), is only forty-six.

pointing to the centre of the spindle and linked with one of its peripheral fibrils* (fig. 3). When viewed from either pole of the spindle the chromosomes form a star-shaped figure around its equator; this phase is therefore termed the *equatorial* or *aster phase*. The plane of the chromosomes is the *equatorial plate*. The spindle attachment of the chromosome is often termed the *centromere*; its position is constant for any single chromosome.

3. *Anaphase*.—The centromeres split into two halves which repel each other and the two constituent chromatids of each chromosome separate and travel in opposite directions along the fibrils of the achromatic spindle to group themselves around the centrosomes. Each group contains the same number of chromatids as there were chromosomes in the equatorial plate, and of these half are maternal in origin and derived originally from the ovum, and half paternal and derived originally from the sperm.

4. *Telophase*.—The chromatids lose their fixability and can no longer be identified as discrete elements. The nuclear membrane and the nucleolus reappear and the cytoplasm undergoes constriction around the equator of the achromatic spindle. The constriction deepens and the original cell is gradually divided.

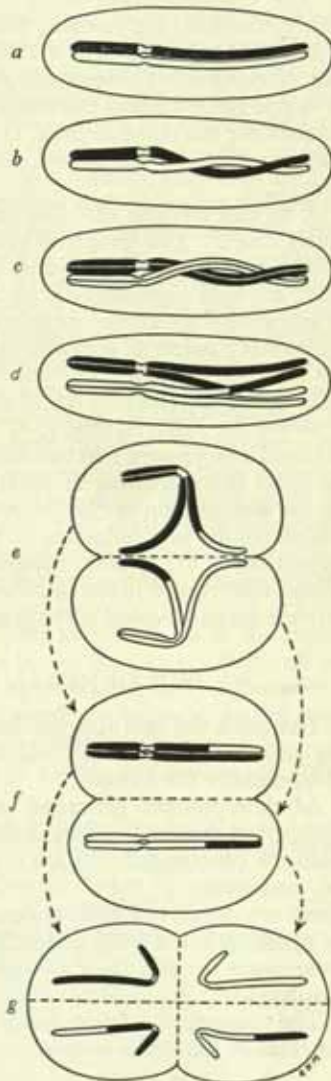
Homotypical and heterotypical division.

—In all somatic cells the process of indirect cell-division conforms to the type described above, and is called *homotypical*. On its completion the nucleus of each daughter cell has as many chromosomes as were present in the nucleus of the mother cell. Since the chromosomes are the bearers of the genes (p. 65) and since each chromosome in one daughter cell is genetically identical with one of the chromosomes in the other daughter cell, mitosis is an *equating division*, as regards both the number of the chromosomes and the distribution of the genes.

Meiosis, or heterotypical division, occurs only in the sex cells during maturation (pp. 59 and 62), and comprises two consecutive divisions. The prophase of the first meiotic division is marked by four stages. In the first (*leptotene*) the chromosomes, which are not yet split into their constituent chromatids, become prominent and stain deeply with basic dyes. They constitute homologous pairs, one member of each pair being paternal and the other maternal in origin. In the second stage (*zygotene*) genetically homologous chromosomes are attracted to each other and lie side by side, each retaining its own spindle-attachment or *centromere*. This process of coupling is termed the *conjugation of the chromosomes* and it is an essential preliminary to the ensuing division (fig. 4).

In the third stage (*pachytene*) the homologous chromosomes become coiled round each other and shortened. Each chromosome splits into two chromatids.

FIG. 4.—A diagram to show the history of two homologous chromosomes in meiosis. (Modified from C. D. Darlington, *Recent Advances in Cytology*, J. and A. Churchill, Ltd.)



a. Conjugation; b. Pachytene—coiling of chromosomes; c. Diplotene—coiling of chromatids; d. Diplotene—uncoiling of chromatids; e. Anaphase of first division; f. Metaphase of second division; g. Completion of second division—note that the chromatids in each of the four nuclei are all different from one another.

* For a detailed account see *Recent Advances in Cytology*, by C. D. Darlington, London, 1937 and, *Animal Cytology and Evolution*, by M. J. D. White, 2nd edition, London, 1954.

In the fourth stage (*diplotene*) the homologous chromosomes move apart except at certain points termed the *chiasmata*. At these two chromatids, one from each chromosome, break and then join diagonally; an exchange of segments thus occurs between them. In this manner an exchange of material is effected between the homologous chromosomes, one of which is maternal and the other paternal in origin. This phenomenon is called a *crossover* (fig. 4d). Finally the chromosomes uncoil and slip apart. The shortening of the chromosomes noted in the pachytene stage has continued to this stage, which is often termed *diakinesis*.

The changes which occur in the metaphase and anaphase resemble those already described for mitosis, with the all-important exception that during the anaphase the *centromeres do not divide* and the homologous chromosomes drag their pairs of chromatids to opposite poles of the spindle. Each of the two cells arising in the telophase therefore possesses one half of the number of chromosomes that is standard for the somatic cells, i.e. the *haploid* instead of the diploid number. In addition, owing to the cross-over, there has been a redistribution of the genetic material.

A second meiotic division follows closely after the first, with practically no resting stage. The prophase is short or may be omitted. In the metaphase the centromeres are attached round the equator of the spindle, while the chromatids, which are held together only by the centromere, float out into the cytoplasm. In the anaphase the centromere splits and the two halves repel each other, homologous chromatids passing to opposite poles of the spindle. In this way, in the telophase, four cells (*gametes*) are derived from the two cells of the first meiotic division. Each has the haploid number of chromosomes and each has its own particular share of the genetic material (fig. 4, g).

It will now be seen that two features distinguish a meiotic from a mitotic division. The latter is an equating division as regards both the number of the chromosomes and the distribution of the genetic material. On the other hand, the first meiotic division results in a reduction in the number of chromosomes by one half and in a segregation of the genetic material. The second meiotic division is an equating division with regard to the number of the chromosomes (i.e. it is a homotypical division) but not with regard to the genetic material, which undergoes further segregation.

THE GENERAL STRUCTURE OF THE BODY

The cell is the unit of structure of the body, and the body consists of innumerable cells and the products of their activities, which include the formation of certain fluids, notably the blood.

As development proceeds, groups of cells become differentiated from one another and are built up in different patterns to form the *tissues* of the body, in which the constituent cells are immobilised. Some of the cells of the body remain free, and many of them circulate in the body fluids, particularly in the blood. Others are capable of independent movement and are able to migrate actively from one situation in the body to another, although they can only do so when the density of the tissue permits their passage or when fluid-occupied spaces in the tissue can be utilised.

The tissues, the body fluids and the 'free' cells will be dealt with in the immediately following sections.

THE TISSUES OF THE BODY

There are five widely distributed basic tissues which are built up, in varying proportions, to form the organs within the body, the body-wall by which they are enclosed and the appendages of the body. They are:—(1) epithelium, (2) connective tissue, (3) sclerous (or skeletal) tissue, (4) muscular tissue, and (5) nervous tissue. Each of these possesses certain distinguishing features and, with the exception of nervous tissue, each is subdivided into a number of varieties, which retain the essential characters of the parent tissue but exhibit specialisation of one or more of its constituent elements. The connective and the sclerous (or skeletal) tissues have many morphological features in common and are often grouped together, but they differ very noticeably in their physical properties, for the connective tissues are soft and pliant, while the sclerous tissues are hard and rigid.

EPITHELIUM

The surfaces of the body—the external surface of the skin, the internal surfaces of the digestive, respiratory, and urogenital systems, the closed serous cavities, the inner coats of the vessels, the acini and ducts of all secreting and excreting glands, the ventricles of the brain and the central canal of the spinal medulla—are covered with one or more layers of cells, called *epithelium* or *epithelial cells*. These cells serve various purposes. Thus, in the skin, the main purpose served by the epithelium (here called the *epidermis*) is that of protection; as the keratinised cells on the surface are worn away by the agency of friction new cells are formed in the deeper layers, and thus the true skin and the vessels and nerves which it contains are defended from damage. The epithelial cells of the salivary glands, the pancreas, the gastric glands, and the glands of the small intestine secrete the digestive juices; those covering the intestinal villi are concerned with the absorption of the products of digestion; those lining the serous cavities provide a smooth, moist surface.

FIG. 5.—Simple, pavement, epithelium.



The constituent cells of an epithelium are always closely packed together and the inter-cellular substance is reduced to a minimum. The cells are arranged in one or more layers, usually supported on a basement-membrane (p. 18), and united together by cement-substance, which is similar in chemical composition to the matrix or ground-substance of the connective tissues, and has the property of reducing nitrate of silver. With few exceptions blood vessels are absent from epithelia, which usually depend for their nutrition on the blood vessels in the underlying connective tissue. The epithelial cells together with their supporting basement membrane and connective tissue constitute a functional unit or *membrane*. In some places, such as the digestive, respiratory and urogenital systems, the internal surfaces are moistened by a film of mucus and the membrane is known as a *mucous membrane*. In other situations, as in the closed cavities of the body, the surfaces are moistened by a film of thin watery fluid and the lining membranes are termed *serous membranes*. Epithelia naturally fall into two groups. In the one there is a single layer of cells (*simple epithelium*); in the other there are several layers (*stratified epithelium* and *transitional epithelium*).

Simple epithelium.—The different varieties of simple epithelium are pavement, columnar, and ciliated.

Pavement epithelium (fig. 5) is composed of flattened cells of different shapes, usually polygonal, and varying in size. These cells fit together by their edges, like the tiles of a mosaic pavement. The nucleus is generally flattened, but may be spheroidal. This kind of epithelium forms the lining of the alveoli of the lungs, covers the serous membranes, and lines the heart, blood-vessels and lymphatics. In the pulmonary alveoli the lining epithelium is entodermal in origin, but in the other instances cited it is derived from the mesoderm. It is usually termed *endothelium* where it lines the blood-vascular system, and *mesothelium* where it lines the serous cavities of the body. Mesothelia are said to be regenerated from connective tissue, whereas epithelial cells are renewed, after destruction, from neighbouring epithelial cells only.

Columnar or cylindrical epithelium (fig. 6) consists of cylindrical or rod-shaped cells set together so as to form a complete layer, resembling, when viewed in profile, a palisade. The cells have a prismatic figure, owing to mutual pres-

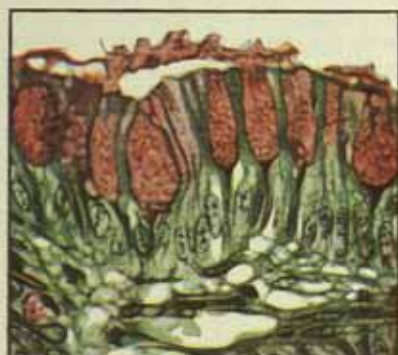
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FIG. 6.—Columnar epithelial cells, from small intestine of cat, stained with hæmatoxylin and eosin. $\times 900$.



sure, and are set upright on the surface which supports them. The cell-protoplasm is always more or less reticulated; the nucleus is oval in shape and contains an intranuclear network; the centriole is double and lies near the surface of the cell. In the columnar epithelium of the intestinal villi the free border of each cell shows a refractive cap, which exhibits well-defined vertical striations. Columnar epithelium lines nearly the whole gastro-intestinal tract

FIG. 7.—Goblet cells *in situ* in the mucous membrane of the small intestine. Human. $\times 450$. Prepared by the periodic-Schiff technique and counterstained with methyl green.



and its glands, the greater part of the male urethra, the vas deferens, the tubules and ducts of the prostate, the bulbo-urethral glands and the vestibular glands. In a modified form it also covers the ovary. Short columnar cells in which the height and width are about equal, as in the lining of the ducts, are frequently termed *cuboidal*

Goblet- or chalice-cells (fig. 7) are modified columnar cells. Each appears to be formed by an alteration in shape of a columnar cell (ciliated or otherwise) consequent on the formation in the interior of the cell of granules which consist of a substance called *mucinogen*. This distends the upper part of the cell, and presses the nucleus down towards its deep part, until the cell bursts and the mucus is discharged on to the surface of the mucous membrane (fig. 7), the cell then assuming the shape of an open cup or chalice. Mucinogen and mucus are stained metachromatically with toluidine blue and thionin and give a positive

reaction with the periodic acid-Schiff technique. A double centriole is found in the mucin-containing part of the goblet-cell. Cells of this kind are especially numerous in the mucous membrane of the stomach, and in the glands of the large intestine;

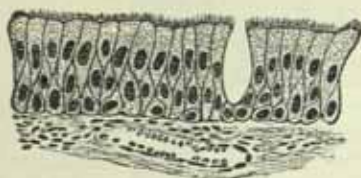
FIG. 8.—Isolated cells from a rabbit's liver (dissociated). $\times 500$.



they also occur in the epithelial covering of the villi of the small intestine and in that lining the respiratory tract.

The epithelium of glands is usually columnar, but in some the cells are cubical in shape, in others they are polyhedral. The protoplasm shows a fine reticulum,

FIG. 9.—Ciliated epithelium from the trachea of a kitten. $\times 255$.



which gives to the cells a granular appearance (fig. 8). Besides these protoplasmic 'granules', gland-cells usually contain true granules which are the products of their own activity. These are in many cases zymogenic in nature, that is, they are, or contain, the precursors of enzymes or ferments.

Ciliated epithelium (fig. 9) is generally columnar in shape. It is distinguished by the presence of minute processes, resembling eyelashes (cilia), standing up from the free

surface. Ciliated epithelium lines the respiratory tract from the nose downwards as far as the respiratory bronchioles (except in the lower part of the pharynx and on the surfaces of the vocal folds); the tympanic cavity and auditory tube; the uterine tube and isolated areas of the cavity of the uterus in the infant; the efferent ductules of the testis, the lobules of the epididymis and the first part of the ductus deferens in

the infant; the ventricles of the brain and the central canal of the spinal medulla where it is termed *ependyma*. In some ciliated epithelia the cells do not all extend to the surface and their nuclei are then placed at different levels, thus simulating stratified epithelium. This type is termed *pseudo-stratified columnar ciliated epithelium*.

Stratified epithelium (figs. 10 and 11) consists of several layers of cells. The cells vary greatly in shape; those of the deepest layer are for the most part columnar and are placed vertically on the basement-membrane; superficial to these the succeeding layers consist of polyhedral cells, which become more and more compressed as they approach the surface; the most superficial cells are found to consist of flattened scales (fig. 10), which overlap one another so as to present an imbricated appearance. The epithelium of the skin is peculiar (fig. 11); it shows several distinct layers of cells arranged in two zones. The deeper zone (*zona germinativa*) consists of a single layer of columnar cells (*stratum basale*) and a more superficial layer of variable thickness composed of polyhedral cells (*stratum spinosum*). In ordinary histological preparations the cells in this stratum appear to be separated by intercellular channels across which pass cytoplasmic processes connecting adjoining cells and containing fine fibrils termed the *tonofibrils*. When a cell is isolated it appears to be covered by a number of short spines representing the broken cytoplasmic processes, hence the term *prickle cells*, for the cells of the stratum spinosum. Electron microscope studies, however, have not confirmed this interpretation* and the presence of tonofibrils cannot be demonstrated in the living cells.

The more superficial zone (*zona cornea*) is arranged in three strata of cells. The deepest layer (*stratum granulosum*) consists of fusiform cells containing an accumula-

FIG. 10.—Stratified squamous epithelium from the œsophagus. (Human.) Stained with hæmatoxylin and eosin.

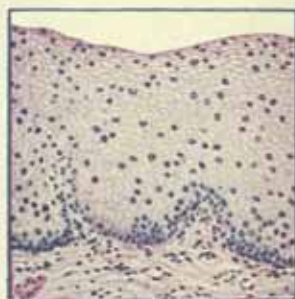
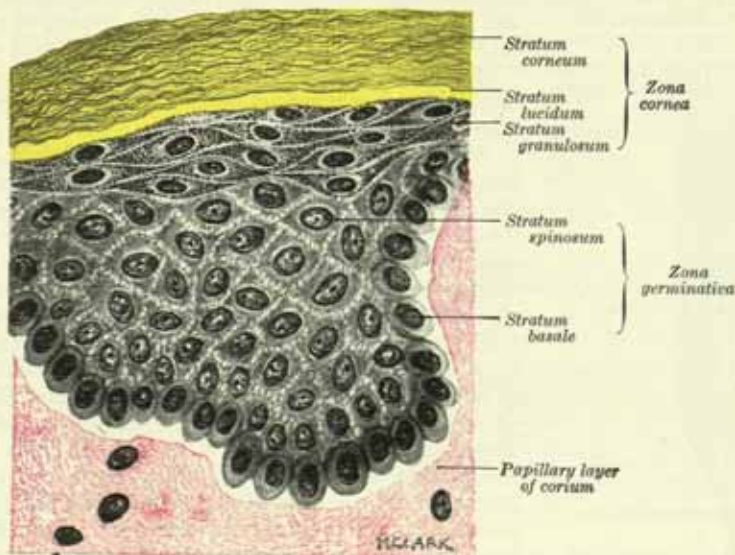


FIG. 11.—A section through the epidermis of the skin of the sole of the foot. Van Gieson's stain. $\times 500$.



tion of readily stainable granules of *eleidin* (Ranvier) in their cytoplasm. The next layer (*stratum lucidum*) is a hyaline layer and is seldom coloured by histological stains. The eleidin granules have been converted into *keratohyalin* in this layer.

* D. C. Pease, *Am. J. Anat.*, 89, 1951.

The stratum lucidum is not always defined and is usually seen only in the thick stratified epithelium covering the palms of the hands and soles of the feet. In the third and most superficial layer (*stratum corneum*) the cells are largely converted into a horny material known as *keratin* and have lost their nuclei. Stratified squamous epithelium occurs in the skin, conjunctiva, on the anterior surface of the cornea and in the mucous membrane of the mouth, lower part of the pharynx, oesophagus, vagina and part of the cervix uteri. Where the surfaces are moist the superficial stratum of cells, though flattened and degenerating, still retain their nuclei and cell outlines.

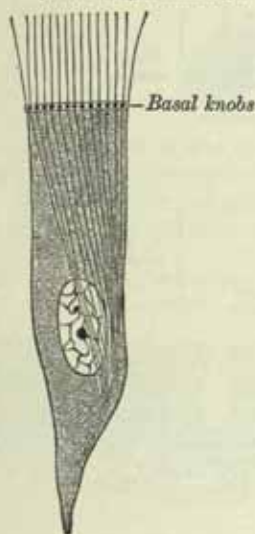
FIG. 12.—Transitional epithelium from urinary bladder. (Human.) Stained with hæmatoxylin and eosin.



cells of the second layer, which are pear-shaped, the apices touching the basement-membrane. Between the tapering points of the cells of the second layer is a third variety of cells of smaller size than those of the other two layers (fig. 12). In the distended condition of the bladder the superficial cells are more flattened, and the pear-shaped cells are shorter and broader than they are when the bladder is contracted.

Pigmented epithelial cells are found in various parts of the body. They form the external layer of the retina, and are present on the posterior surface of the iris, in the olfactory region of the nose, in the membranous labyrinth of the ear, in the deeper layers of the cuticle, and in the hairs. Pigment is abundantly present in the skin of the coloured races, but in the skin of white races it is well-marked only in the areolæ round the mammary papillæ and in irregular coloured patches. The pigment granules are very small in size and they are crowded together within the cells but they do not invade the nuclei. Freckles are due to the presence of granules of a yellow pigment in groups of cells in the cuticle.

FIG. 13.—A ciliated cell (semi-diagrammatic).



Surface modifications of epithelial cells.—Many epithelial cells show modifications of their free surfaces. The superficial cells of transitional epithelium are covered at their exposed surface by a densely staining *cuticular border*. In the columnar epithelium of the intestine, of the gall bladder and of some of the tubules of the kidney the free surface of the cells shows a regular fine vertical striation known as the *striated* or *brush border* (fig. 6). This appearance is variously interpreted as due to minute non-motile hair-like outgrowths of the cell or a series of finely packed ductules leading into the cytoplasm.*

Striated borders are seen particularly in epithelia believed to be specialised for absorption. Certain epithelial cells (p. 8) are provided with motile threadlike *cilia*, the rhythmic wave-like beating of which helps in the elimination of secretion and foreign particles from their surfaces. At the base of each cilium is a *basal knob* or *granule* believed to be of centriolar origin. From the basal knob fine filaments or roots often extend deeply into the cytoplasm of the cell (fig. 13). Electron microscopy

reveals that each cilium consists of a filamentous extension of the cytoplasm, enclosed in a prolongation of the cell membrane and containing eleven filaments. Of these two are centrally placed and nine form a circle around them. Basally they can be

* J. Baker, *Quart. J. Med. Sci.*, 94, 1942.

traced to the basal knob which is an elongated body curved in the plane of ciliary movement * (fig. 13).

Electron and phase contrast microscopy reveals also that the free surfaces of many epithelial cells which have hitherto been considered to be plane and un-specialised, are provided with fronds, streamers and *microvilli*. The latter are less regular than and lack the complicated fibrillar structure of cilia. Microvilli have been described on the epithelial cells of the thyroid gland, choroid plexuses, tubules of the kidney, mesothelial cells and elsewhere. Large non-motile processes occur on the epithelial cells of the epididymis and the columnar cells lining the central canal of the spinal medulla. These are termed *stereocilia*.

A cement substance unites epithelial cells to one another. The cells of the columnar epithelium of the alimentary tract however are believed by some to be separated by 'intercellular spaces', closed at the surface by a dense cement which forms the *terminal bars*, outlining, in stained sections, the superficial borders of the cells.

THE CONNECTIVE TISSUES

Connective tissues are derived from the mesenchyme, and include a number of tissues which have a passive function, that of binding together or supporting the functionally active structures. They differ considerably from each other in appearance, but present many points of relationship.

In a connective tissue the parent cells are separated more or less widely from one another by a homogeneous matrix or ground substance, in which fibres may or may not be present. The most generalised form of connective tissue is termed *areolar tissue* and in it the constituent cells are separated by a semi-fluid matrix in which both white connective tissue and yellow elastic fibres are found (fig. 14). As contrasted with this generalised form, specialised forms occur in which (a) the cells, or (b) the matrix, show differentiating characters. In *adipose tissue*, the constituent cells are modified to enable them to contain droplets of oil; in *white fibrous* and *yellow elastic tissue*, it is the fibres which predominate.

Areolar tissue (fig. 14) is so called because, when artificially distended with air

FIG. 14.—Subcutaneous areolar tissue from a rabbit. The inset at the lower right hand corner represents another part of the same slide under a high-power. Stained with aniline blue.



or fluid, it exhibits intercommunicating areolæ or spaces. It is extensively distributed and its chief use is to bind parts together, though allowing, in virtue of its extensibility and elasticity, a considerable amount of movement to take place. It occurs as subcutaneous tissue in animals which possess a hairy coat, as the sub-mucous coat in the digestive tract, and as subserous tissue. It is also found between

* D. W. Fawcett and K. R. Porter, *J. Morph.*, 84, 1954.

muscles, vessels, and nerves, forming investing sheaths for them, and connecting them with surrounding structures. It is present in the interior of organs, binding together the lobes and lobules of the compound glands, the various coats of the hollow viscera, and the fibres of muscles and nerves.

When areolar tissue is stretched it is seen to be made up of soft elastic threads, resembling spun silk, and interlacing in all directions. A thin layer, examined under the microscope, shows fibres and cells, imbedded in a ground-substance or *matrix*.

The matrix is a semifluid gelatinous substance containing a high proportion of mucosubstances rich in chondroitin sulphuric acids and hyaluronic acid. It is preserved by the freezing-drying method of preparation and stains metachromatically with toluidine blue.

The fibres form an irregular meshwork, and are of two kinds—white and yellow. The *white* or *collagenous* fibres are exceedingly fine; they are colourless, homogeneous and transparent, and are arranged parallel with each other in bundles which have a wavy course. The individual fibres do not branch,

FIG. 15.—Electron micrograph of collagen fibres from human tendo calcaneus. $\times 34,000$. Specimen shadowed with palladium-gold alloy.

Prepared and kindly lent by Miss S. Fitton Jackson.



but small bundles of them may leave one large bundle to join another. They measure from 2μ to 100μ in diameter and show a fine longitudinal striation under the conventional light microscope. Electron microscopy reveals that the individual fibres consist of bundles of minute fibrils of about 800 \AA to $5,000 \text{ \AA}$ * (fig. 15). Whether these fibres are to be regarded as derivatives of the ground substance or of the cells of the tissue has given rise to much discussion. Recent work shows that they arise predominantly extracellularly and that they owe their origin to the activity of the fibroblasts, which probably contribute fibrogenic material to the surrounding matrix (fig. 16).†

The *yellow* or *elastic* fibres are highly refractile and therefore have well-defined outlines. They are usually somewhat larger than the white fibres and are pale yellow in colour and homogeneous in appearance. They run a comparatively straight course, branch and join up freely with each other. When they are broken across, the ends tend to curl up. They differ from the white fibres in their resistance to boiling and to dilute acids and alkalis and also in their staining reactions; they stain a dark red colour with orcein.

The cells of areolar tissue are of five principal kinds; (1) Flattened *lamellar cells* or *fibroblasts*, which are thin and spindle-shaped when seen in profile, but are irregular in outline with branching processes when seen on the flat. They are composed of clear protoplasm, with few granules, and contain oval nuclei; their processes may unite with those of neighbouring cells, as in the cornea. (2) *Histiocytes* are large irregular cells characterised by the presence of granules or vacuoles in their protoplasm, and containing oval nuclei. They are both amoeboid and phagocytic, but are difficult to distinguish from fibroblasts in fixed preparations. They can be identified with certainty by their marked ability to store certain colloidal substances, such as trypan blue, when injected supravitaly. (3) *Mast cells* are ovoid or spheroidal in shape and contain basophil granules. They are not numerous in human connective tissue and are believed to be concerned with the formation of heparin.

(4) *Fat cells* (see adipose tissue). (5) *Plasma cells* are rare in healthy connective tissue and are round or oval in shape with a small eccentrically placed nucleus

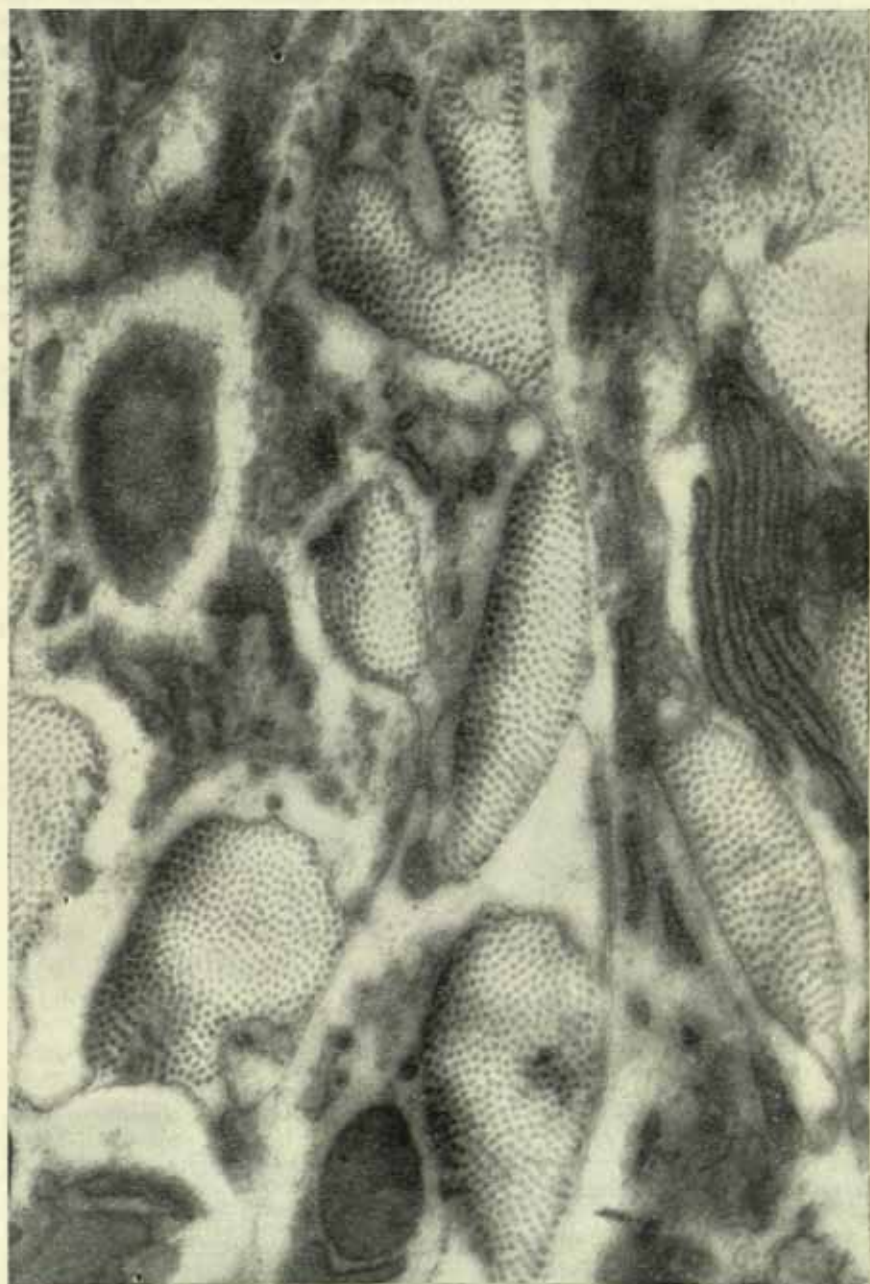
* F. O. Schmitt, C. E. Hall and M. A. Jakus, *J. Cell. Comp. Physiol.*, **20**, 1942.

† S. Fitton Jackson, *Proc. Roy. Soc. B.*, 1956. For other details see J. T. Randall, *Nature Structure and of Collagen*, London, 1953.

in which the chromatin is arranged in clumps around the periphery, resembling the spokes of a cartwheel. They are believed to be derived from lymphocytes.

FIG. 16.—Electron micrograph of a section of developing tendon from a 14-day chick embryo. The collagen fibres which are about 250Å in diameter are seen in transverse section and are closely interlocked with the cytoplasm of adjacent fibroblasts. Each fibre is invested by interfibrillar material containing the collagen molecules used in its subsequent enlargement.
× 24,000.

Lent by Miss S. Fitton Jackson.



In addition to these five types of cells, areolar tissue may contain *wandering cells*, i.e. leucocytes which have emigrated from the neighbouring vessels; in some instances, as in the choroid coat of the eye, cells filled with granules of pigment (*pigment-cells*) are found (p. 17).

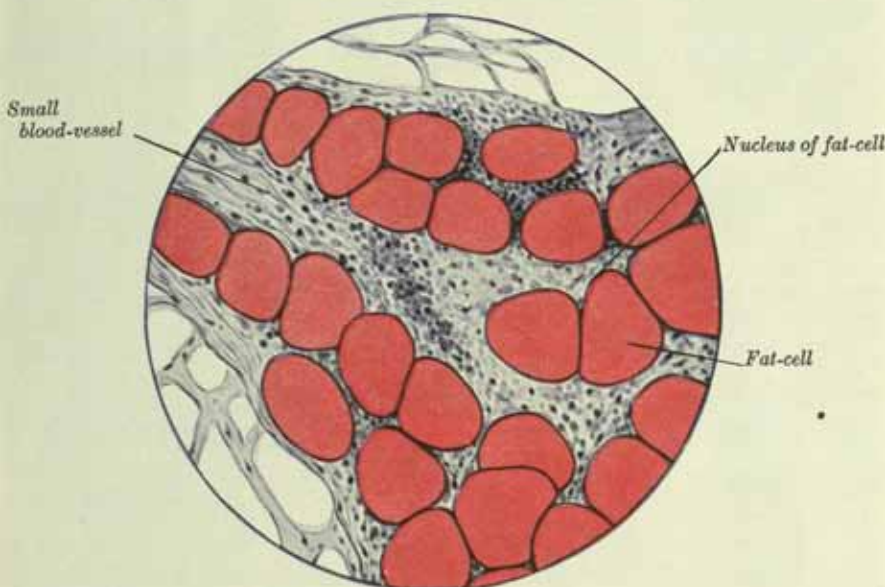
Adipose tissue.—In almost all parts of the body areolar tissue contains a variable quantity of adipose tissue or fat. The principal situations where it is *not* found are the subcutaneous tissue of the eyelids, of the penis and scrotum, and of the labia minora; within the cavity of the cranium; and in the lungs, except near their roots. The distribution of adipose tissue is not uniform; in some parts it is in great abundance, as in the subcutaneous tissue, especially of the abdominal wall, around the kidneys, and in the mesentery and omentum. Lastly, fat enters largely into the formation of the marrow of bones.

Adipose tissue consists of fat-cells, lodged in the meshes of areolar tissue. Fat-cells (fig. 17) vary in size, the average diameter being about 50μ ; each consists of an exceedingly delicate protoplasmic membrane, filled with fatty substance, which is liquid during life, but solidifies after death. They are round or spherical where they are not subjected to pressure; otherwise they are more or less polygonal. A nucleus is always present under the cell-membrane and can be demonstrated by staining with hæmatoxylin; in the natural condition it is so compressed by the contained oily matter as to be scarcely recognisable. The fat-cells are held together mainly by the network of delicate connective tissue, carrying capillary blood-vessels which are distributed to them.

Chemically the oily material is composed of olein, palmitin, and stearin, which are glyceryl esters of fatty acids. Sometimes fat-crystals form in the cells after death. When the tissue is boiled in ether or strong alcohol, the fat is extracted from the cells, which are left empty and shrunken.

Fat first appears in the human embryo about the fourteenth week. The fat-cells are formed by the transformation of undifferentiated mesenchyme cells, provided

FIG. 17.—Adipose tissue, from the omentum. Stained with Sudan III. and hæmatoxylin. $\times 350$.



with processes and indistinguishable from fibroblasts.* Minute refractile droplets of oil accumulate in the cytoplasm of the cell, which loses its processes and becomes rounded in shape. The droplets increase in number and coalesce to form a large globule, which distends the cell and displaces the nucleus towards the periphery (fig. 17).

White fibrous tissue is a true connecting structure which develops in response to tensile strains in situations where strength is required without rigidity or elasticity. It serves three purposes in the animal economy. In the form of ligaments it binds bones together and limits the range of movements at joints; in the form of tendons it connects muscles with bones or other structures; it constitutes investing or protecting membranes to various organs. Examples of

* E. R. and E. L. Clark, *Amer. J. Anat.*, 68, 1940.

such membranes are to be found in the fasciæ or sheaths of the muscles, the periosteum, and the perichondrium; the capsules of the various glands; the investing sheaths of the nerves (perineurium) and of various organs, such as the penis and the eye.

In white fibrous tissue, as its name implies, the white fibres predominate; the matrix is apparent only as a cement-substance, yellow elastic fibres are comparatively few, while the tissue-cells are arranged in a special manner. It presents to the naked eye a silvery white, glistening appearance; it is inelastic, and is only very slightly extensible; it is exceedingly strong, so that upon the application of any external violence, a bone with which it is connected may fracture before the fibrous tissue gives way. In ligaments and tendons the bundles of fibres run parallel with each other (fig. 18); in membranes they intersect one another. The cells found in white fibrous tissue are often called 'tendon-cells'. They are situated on the surfaces of groups of fibres, and are arranged in single rows, each cell being separated

FIG. 18.—Longitudinal section of human tendo calcaneus. $\times 157$. Stained with hæmatoxylin and eosin.



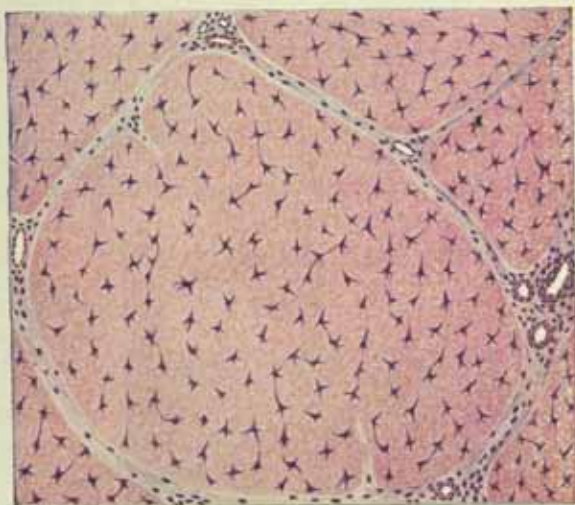
from its neighbours by a narrow line of cement-substance. The nucleus is generally situated at one end of the cell, the nucleus of the adjoining cell being in close proximity to it. The tendon-cells have wing-like processes which pass between the bundles of fibres, giving a stellate appearance in transverse section (fig. 19). When viewed from the side, the cell with its wings is quadrangular, and there may be the appearance of a vertical line on the body of the cell owing to the projection of a wing towards the eye of the observer. Upon the addition of acetic acid, white fibrous tissue swells up into a glassy-looking indistinguishable mass. When boiled in water it is converted almost completely into gelatin, the white fibres being composed of *collagen*, which is regarded as the anhydride of gelatin.

In many situations in the body a tissue is present which, though lacking the density of white fibrous tissue, has a higher proportion of collagenous fibres than are commonly present in areolar tissue. It may conveniently be termed *fibro-areolar tissue*.

Yellow elastic tissue.—In certain parts of the body a tissue is found which is of a yellowish colour, and possessed of great elasticity. It is capable of considerable extension, and when the extending force is withdrawn returns at once

to its original condition. This is *yellow elastic tissue*; it may be regarded as a connective tissue in which the yellow elastic fibres have developed to the practical exclusion of the other elements. It is found in the ligamenta flava

FIG. 19.—A transverse section through a human tendon. $\times 100$.
(After Sobotta.)



(fig. 20), in the vocal folds and the cricovocal membrane of the larynx, in the mucous membrane of the trachea and bronchi, in the walls of the pulmonary air-vesicles, in the coats of the blood-vessels, especially the larger arteries, and to a very considerable extent in the thyrohyoid and stylohyoid ligaments. It is also found

FIG. 20.—Longitudinal section of human ligamentum flavum. $\times 280$.
Stained with orcein.

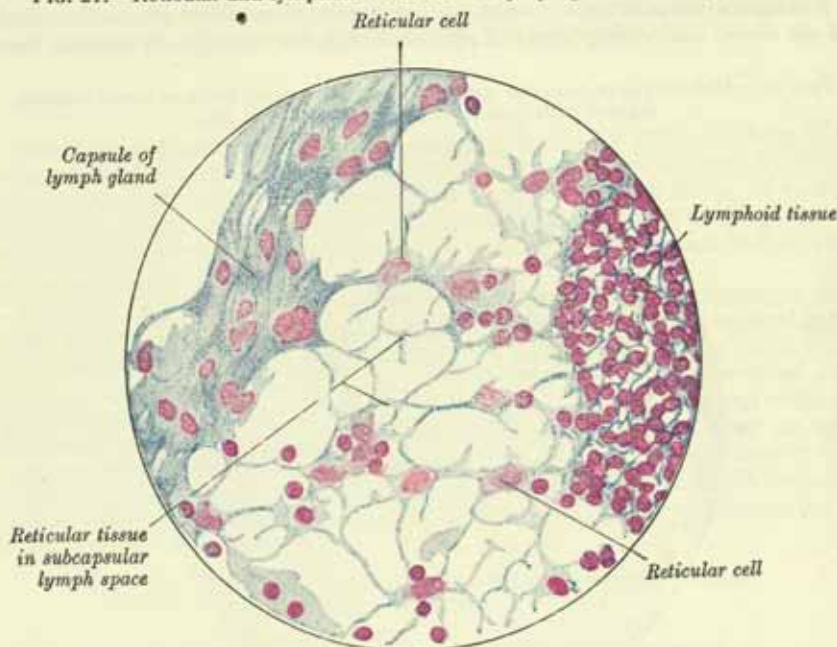


in the ligamentum nuchæ of the lower animals. Where the fibres are broad and large and the network close, the tissue presents the appearance of a membrane, with gaps or perforations corresponding with the intervening spaces. This

is found in the inner coat of the arteries, and the media of large arteries; to it the name of *fenestrated membrane* was given by Henle. Yellow elastic fibres remain unaltered by acetic acid; chemically they are composed of the sclero-protein known as *elastin*.

Reticular tissue (fig. 21) is found extensively in many parts of the body, constituting the framework of some organs and entering into the construction of many mucous membranes. It is a variety of connective tissue in which the ground-substance is, in a great measure, replaced by fluid. It is composed of extremely fine argyrophilic fibres which branch and form an intricate network. Closely associated

FIG. 21.—Reticular and lymphoid tissue from a lymph gland. Mallory's stain.



with this network, particularly at its intersections, are *reticular cells*, many of which exhibit well marked phagocytic properties. The nature of the reticular fibres is the subject of dispute. Although they differ in many of their characteristics from collagen fibres they are believed by many to be very fine or immature collagen fibres. In many situations the interstices of the network are filled with rounded lymph-corpuscles, and the tissue is then termed **lymphoid tissue**.

Mucoid tissue is a foetal or embryonic type of connective tissue, found chiefly as a stage in the development of connective tissue from mesenchyme. It exists in the 'jelly of Wharton', which forms the bulk of the umbilical cord, and consists of a matrix, largely made up of muco-substances, in which nucleated cells with branching and anastomosing processes are found (fig. 22). Few fibres are seen in typical mucoid tissue, though at birth the umbilical cord shows a considerable development of fibres; after birth it is still to be seen in the pulp of a developing tooth. In the adult the vitreous body of the eye is a persistent form of mucoid tissue, in which the fibres and cells are very few in number.

Neuroglia is a specialised form of connective tissue found only in the nervous system. It is described on p. 38.

Pigmented connective tissue-cells are frequently met with in the lower vertebrates. In man they are found in the choroid coat of the eye and in the iris of all but the light blue eyes and the albino. The cells are usually large and branched, and are filled with brown or black granules, consisting of *melanin*. The pigment-granules are of very small size and are closely packed within the cells, but do not invade the nuclei.

Applied Anatomy.—Congenital absence of pigment from the skin and other tissues constitutes the condition known as albinism. Localised patches of skin from which pigment is absent are found in leucoderma; linear white streaks may result from old

scars or from overdistension of the skin, particularly that over the abdomen following pregnancy or ascites. A congenital excessive pigmentation may be general, or may occur locally in the form of dark brown or black *nævi* (moles). Pigmented patches occasionally follow the continued action of local irritants, and a general swarthinness may result from excessive exposure to the sun, particularly in association with uncleanness (*vagabondinismus*). Disorders of the endocrine organs may be associated with much discoloration of the skin; this is particularly noticeable in Addison's disease (suprarenal glands) where the normally pigmented parts of the body show increased pigmentation and pigmented patches occur also in the buccal and lingual mucous membranes. In pregnancy and in some uterine disorders patches of discoloration may be seen round the nipples, over the *linea alba*, and on the face.

Basement-membranes consist of thin sheets of modified connective tissue, and are found underlying layers of epithelial cells, for example, in mucous mem-

FIG. 22.—Mucoid tissue from the umbilical cord of a human *fœtus* of seven months, stained with hæmatoxylin and eosin. $\times c. 250$.



branes and secreting glands. They may be formed of cells or of condensed ground-substance. In the former case, flattened cells, which are modified fibroblasts, are united by their edges by means of cement-substance, which can be demonstrated by staining with silver nitrate; if the cells are unbranched, the membrane is continuous; if they are branched, the processes are united, and the membrane is fenestrated. When the membrane is devoid of cells it consists of a lamina of ground substance in which is embedded a network of argyrophilic fibres. The ground substance is blackened by silver nitrate and gives a positive reaction with the periodic acid-Schiff technique. The basement-membrane underlying the epithelium on the anterior surface of the cornea is composed of ground-substance.

Vessels and nerves of connective tissue.—The *blood-vessels* of connective tissue are very few—that is to say, few are supplied to the tissue itself, although many carrying blood to other structures may permeate one of its forms, viz. areolar tissue. In white fibrous tissue the blood-vessels usually run parallel to and between the longitudinal bundles, sending communicating branches across the bundles; in some of its forms, as in the periosteum and dura mater, they are fairly numerous. In yellow elastic tissue the blood-vessels also run between the fibres. *Lymphatic vessels* are very numerous in most forms of connective tissue, especially in the areolar tissue beneath the skin and the mucous and serous surfaces. They are also found in abundance in the sheaths of tendons, as well as in the tendons themselves. *Nerves* are found ending in white fibrous tissue (p. 457); but it is doubtful whether any nerves end in areolar tissue; at all events, they have not yet been demonstrated, and the tissue is possessed of very little sensibility.

THE SCLEROUS TISSUES

The sclerous (or skeletal) tissues provide the stiffening which is essential for the formation of the general framework of the body. Structurally they are closely allied to the connective tissues, for their constituent cells lie in a matrix in which fibres may, or may not, be developed. Physically, however, the sclerous tissues differ from the soft, pliant connective tissues, for the matrix has become solidified.

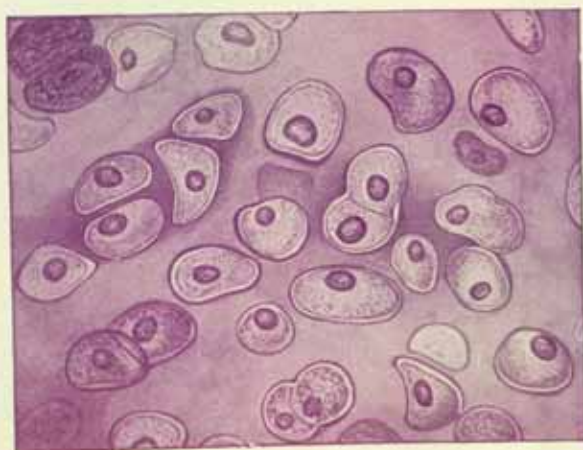
There are two varieties of sclerous tissue, viz. cartilage, or gristle, and bone. In cartilage the matrix is composed largely of muco-substances rich in chondroitin sulphates. In bone the matrix is impregnated with certain inorganic salts, of which calcium phosphate forms much the greatest proportion.

CARTILAGE

Cartilage is found in various parts of the body—in the joints, parietes of the thorax, trachea, bronchi, nose, and ears—where it is necessary to have rigidity and strength combined with a certain degree of elasticity. In the fœtus, at an early period, the greater part of the skeleton is cartilaginous; as this cartilage is afterwards replaced by bone, it is called *temporary*, in contra-distinction to that which remains unossified and is called *permanent*.

Cartilage, though relatively non-vascular, is penetrated by numerous small canals, each of which conveys a small artery and one or more veins surrounded by loosely arranged fibrous tissue derived from the perichondrium. In the laryngeal and nasal cartilages vascular canals begin to form in the seventh month of intra-uterine life and persist until old age. In costal cartilage the canals appear in the first year but do not reach the centre of the shaft until the 10th year. After the age of 20 marrow elements are said to be present, the cells of which undergo atrophy about the 60th year, leaving the canals occupied by a mucinous material. In temporary cartilage vascular canals begin to appear in the third month of intrauterine life

FIG. 23.—A section of hyaline cartilage from the trachea. Human.
Hæmatoxylin and eosin. ($\times 500$.)



and grow towards, but do not quite reach, the site where the ossific centre subsequently appears. They grow in from the perichondrium in any situation where the surface is not articular and is devoid of tendinous or ligamentous attachments. Hurrell * believes that by the third month of fœtal life the central cells of the larger cartilaginous elements are threatened with starvation and that the vessels contained in the canals bring them the nourishment of which they stand in need, the ingrowth being a response to a chemotaxic stimulus.

* D. J. Hurrell, *J. Anat., Lond.*, 69, 1934.

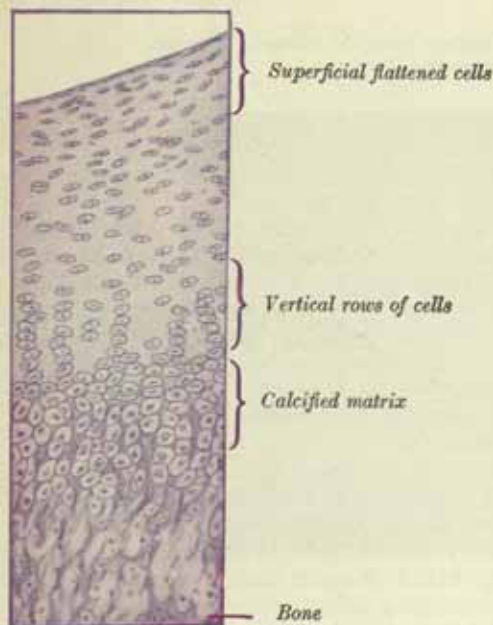
Cartilage is divided, according to its minute structure, into *hyaline cartilage*, *white fibrocartilage*, and *yellow or elastic fibrocartilage*. Besides these varieties met with in the adult human subject, there is a variety called *cellular cartilage*, formed entirely, or almost entirely, of cells, separated from one another only by their capsules, which are extremely well marked in this kind of cartilage. Cellular cartilage is found in the external ears of rats, mice, and some other animals, and it also forms a stage in the development of cartilage in human embryonic life.

Hyaline cartilage has a pearly bluish colour and consists of a gristly mass of a firm consistence, but of considerable elasticity. Except where it coats the articular ends of bones it is covered by a fibrous membrane, named the *perichondrium*. If a thin slice be examined under the microscope, it is seen to consist of cells of a rounded or bluntly angular form, lying in spaces in a granular or almost homogeneous matrix (fig. 23). The cells are frequently arranged in groups of two or more, and, when this is so, they generally have straight outlines where they are in contact with each other, but are rounded in the rest of their circumference. They consist of clear translucent protoplasm in which fine interlacing filaments and minute granules are sometimes present; one or two round nuclei, having the usual intranuclear network, are imbedded in the protoplasm.

When viewed with transmitted light the matrix is transparent and apparently without structure, or else presents a dimly granular appearance, like ground glass. It stains with basic dyes and, owing to the abundance of chondroitin sulphates in it, it stains metachromatically with toluidine blue. The intensity of the staining is more marked around the cell spaces where it forms a dark rim known as the *capsule* of the space. When examined with polarized light or after special treatment* the matrix of hyaline cartilage can be shown to contain fine fibres, many of which have the characters of collagen fibres.

Costal cartilage, temporary cartilage and most of the articular cartilage are of the

FIG. 24.—A vertical section through the lower end of the ulna of a human foetus. Semi-diagrammatic.



hyaline variety, but they present differences in the size, shape and arrangement of their cells.

Articular hyaline cartilage (fig. 24) shows no tendency to ossification; its matrix is finely granular, and its cells are flattened and disposed parallel to the surface in the superficial part of the cartilage, while nearer to the bone they are oval and are arranged in vertical rows. The deepest part, which lies next to the bone, is calcified (fig. 24). Articular cartilage has a tendency to split in a vertical direction. Its free surface is not covered by perichondrium, but the synovial membrane can be traced over a small part of its circumference, and here the cartilage-cells are more or less branched and pass insensibly into the branched fibroblasts of the synovial membrane. It forms a thin layer upon the joint-surfaces of the bones, and its elasticity enables it to break the force of concussions, while its smoothness gives ease and freedom of movement. It varies in

thickness according to the shape of the articular surface on which it lies; where this is convex the cartilage is thickest at the centre, the reverse being the case on concave articular surfaces. The free surface of the cartilage is constantly being worn away throughout life owing to the joint movements, and this wastage necessitates continuous maintenance growth. In the child mitosis is the normal

* A. Benninghoff, *Lehrbuch der Anatomie des Menschen*, I. Munich 1939. M. A. MacConaill, *J. Bone Jt. Surg.*, 33B, 1951.

method of cell division, but at an early age amitotic figures can be observed and in the adult amitosis is the sole mechanism responsible for growth.* Articular cartilage is believed to derive its nutriment from three sources, the vessels of the synovial membrane, the synovial fluid and the blood vessels of the underlying marrow cavity. Many of the latter penetrate into and even through the calcified matrix between the bone and the cartilage.†

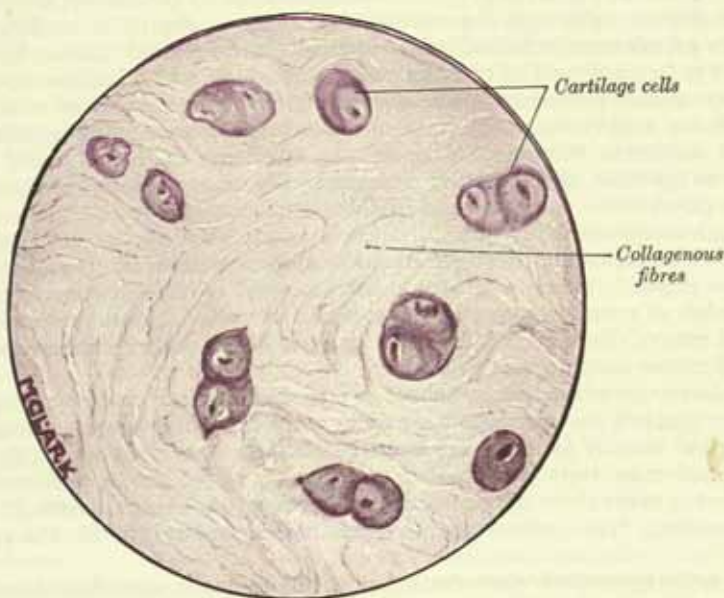
In **costal cartilage** the cells and nuclei are large, and the matrix, which is usually homogeneous and transparent, has a tendency to fibrous striation, especially in old age. In the thickest parts of the costal cartilages a few large vascular channels may be detected. The xiphoid process of the sternum and the cartilages of the nose, larynx, and trachea (except the epiglottis and corniculate cartilages of the larynx, which are composed of elastic fibrocartilage) resemble the costal cartilages in microscopical characteristics. The arytenoid cartilage of the larynx shows a transition from hyaline cartilage at its base to elastic cartilage at the apex.

The hyaline cartilages, especially in adult and advanced life, are prone to calcify—that is to say, their matrix becomes permeated by calcium salts. Calcification occurs frequently in the costal cartilages, and in the cartilages of the larynx, and may be succeeded by ossification.

White fibrocartilage consists of dense white fibrous tissue arranged in bundles, with small, scattered groups of cartilage-cells between the bundles; the cells are roughly ovoid in shape, and are surrounded by concentrically striated areas of cartilage-matrix (fig. 25). When present in bulk, as in the intervertebral discs, it provides a tissue of great strength and rigidity combined with an appreciable degree of elasticity. When present in lesser amount, as in the articular discs (p. 453), the glenoidal and acetabular labra (pp. 485 and 514), and the cartilaginous lining of bony grooves which lodge tendons, it constitutes a tissue of considerable toughness and sufficient elasticity to enable it to resist the effects of pressure and friction.

The articular surfaces of bones which ossify in membrane (p. 26) are

FIG. 25.—White fibrocartilage from the intervertebral disc of a horse. Stained with hæmatoxylin and eosin. Highly magnified.



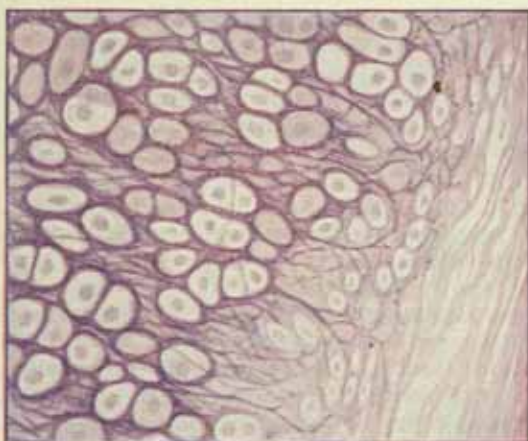
covered with white fibrocartilage and in these situations it serves the same purpose as hyaline cartilage.

* H. C. Elliott, "Studies on Articular Cartilage," *Amer. J. Anat.*, 58, 1936.

† D. E. Holmdahl and B. E. Ingelmark, *Acta Orthop. Scand.*, 20, 1950.

Yellow or elastic fibrocartilage is found in the ears, the corniculate cartilages of the larynx, the epiglottis, and the apical portions of the arytenoid cartilages. It consists of cartilage-cells and a matrix, the latter being pervaded by a network of yellow elastic fibres, branching and anastomosing in all directions, except immedi-

FIG. 26.—Yellow or elastic fibrocartilage from the ear of a sheep, stained with orcein.



ately around the cells, where there is a variable amount of hyaline substance (fig. 26). The fibres resemble those of yellow elastic tissue, not only in appearance and in being unaffected by acetic acid, but also in their affinity for orcein.

BONE

Structure and physical properties.—Bone is one of the hardest structures of the animal body, although it possesses also a certain degree of resilience. Its colour, in a fresh state, is pinkish white externally, and deep red within. In section it is seen to be composed of two kinds of tissue, one of which is dense in texture, like ivory, and is termed *substantia compacta*; the other consists of a meshwork of *trabeculae* within which are easily visible intercommunicating spaces; this is called *substantia spongiosa*. The compact substance is always placed on the exterior of the bone, the spongy in the interior (fig. 249). The relative quantities of these vary in different bones and in different parts of the same bone, according as strength or lightness is requisite. Close examination of the compact substance shows it to be extremely porous, so that the difference between it and the spongy substance depends merely upon the relative amount of solid matter and the size and number of spaces in each; in the compact substance the spaces are small and the solid matter abundant, while in the spongy substance the spaces are large and the solid matter small in quantity.

The trabeculae of the spongy substance are laid down in such a way as to enable them to withstand the stresses to which they are normally subjected. Those which lie along the lines of force are intersected, obliquely or at right angles, by others which function as struts or ties. The arrangement is well shown in X-ray photographs and sections of the upper end of the femur (fig. 441), the calcaneus (Pl. XVII) and elsewhere. The architecture of bones is designed to provide the requisite strength and to eliminate unnecessary weight.

It is to be noted that when the alignment of a bone is altered as the result of union in bad position following fracture, the trabeculae undergo a re-alignment adapted to the altered conditions.

During life bone is permeated by vessels, and enclosed, except where it is coated with articular cartilage, in a fibrous membrane termed the *periosteum*, by means of which many of these vessels reach the bone. If the periosteum be stripped from the surface of the living bone, small bleeding points are seen which mark the entrance

of the periosteal vessels; and on section every part of the bone exudes blood from the minute vessels which ramify in it. In the interior of the long bones of the adult limbs there is a cylindrical cavity (*cavum medullare*) filled with *medulla ossium* or *marrow*, and lined with a membrane composed of highly vascular areolar tissue, called the *endosteum*. This cavity begins to appear in the middle of the shaft in the foetus and extends in both directions until it almost reaches the epiphyseal lines.

The **periosteum** adheres to the surfaces of the bones but it is absent from the cartilage covering their articular surfaces. When strong tendons or ligaments are attached to a bone, the periosteum is incorporated with them. It consists of two layers closely united together, the outer formed chiefly of white fibrous tissue, containing occasionally a few fat-cells; the inner, of elastic fibres of the finer kind, forming dense membranous networks, which can again be separated into several layers. In young bones the periosteum is thick and very vascular, and is separated from the bone by a layer of soft *osteogenetic tissue*, containing a number of granular cells, the *osteoblasts*, by which ossification proceeds on the exterior of the young bone. Later in life the periosteum is thinner and less vascular, and the osteoblasts are represented by a single layer of flattened cells on its deep surface. The periosteum serves as a nidus for the ramification of the vessels previous to their distribution in the bone; hence the liability of bone to exfoliation or necrosis when denuded of this membrane by injury or disease. Lymphatics, which generally accompany the arteries, and free nerve endings (p. 920) may also be demonstrated in the periosteum.

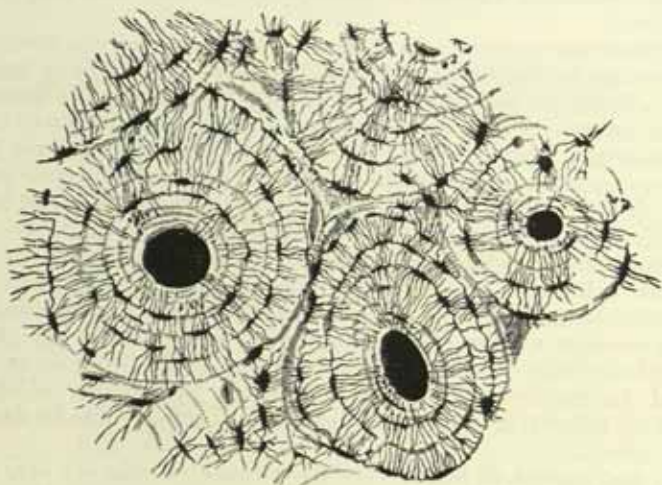
Vessels and nerves of bone.—The *blood-vessels* of bone are very numerous. Those of the compact substance are derived from a close network of vessels in the periosteum. Vessels pass from this network into the minute orifices in the compact substance, and run in the Haversian canals which traverse it. The spongy substance is supplied in a similar way by larger vessels, which perforate the outer compact substance and are distributed to the cavities of the spongy portion of the bone. In the long bones, numerous apertures may be seen at the ends near the articular surfaces; some of these give passage to arteries, but the greater number transmit veins from the spongy substance. The marrow of a long bone is supplied by an artery which enters the bone at the nutrient foramen (*foramen nutricium*). The *nutrient artery*, usually accompanied by one or two veins, sends branches proximally and distally, which ramify in the endosteum and give twigs to the adjoining Haversian canals. The ramifications of this vessel anastomose with the arteries of the spongy and compact substances. In most of the flat, and in many of the short, bones there are one or more large apertures for the transmission of nutrient vessels. In the flat cranial bones the veins are large and run in tortuous canals in the diploic tissue, the walls of the canals being formed by thin lamellæ of bone, perforated here and there for the passage of branches from the adjacent diploë. The same condition is found in all spongy substance, the veins being enclosed and supported by osseous material, and having exceedingly thin coats. When a bone is divided, the vessels remain open, and do not contract in the canals in which they are contained. The presence of *lymphatic vessels* has never been convincingly demonstrated. *Nerves* are said to be most numerous in the articular extremities of the long bones, in the vertebræ, and in the larger flat bones. They are distributed freely to the periosteum, and fine medullated and non-medullated fibres accompany the nutrient vessels into the interior of the bone for the supply of the blood-vessels of the marrow. The acute sensitiveness of bone to painful stimuli leads one to expect that numerous sensory nerves will be found in the bone itself, but the evidence for their presence has hitherto been scanty. However, by the use of a special silver technique, Hurrell* has succeeded in tracing nerve fibres to their termination in the bone matrix and in close relation to osteoblasts.

Minute anatomy.—Compact bone consists mainly of a number of irregularly cylindrical units, or *Haversian systems*, each consisting of a central canal, the *Haversian canal*, surrounded by concentric lamellæ of bony tissue. Between these lamellæ there are a number of small spaces termed *lacunæ*, which are connected with each other and with the central Haversian canal by many fine radiating channels called *canaliculi*. The irregular intervals between these circular districts are

* *J. Anat., Lond.*, 72, 1937.

occupied by *interstitial* lamellae, with their lacunae and canaliculi, running in various directions, but more or less parallel with the surface (fig. 27). Again, other lamellae

FIG. 27.—A transverse section through the compact substance of bone. Magnified. (Sharpey.) (From Quain's *Elements of Anatomy*.)



are found encircling the inner and outer surfaces of the bone; they are termed the inner and outer *circumferential* or *primary* lamellae, to distinguish them from those surrounding the Haversian canal, which are termed *secondary* lamellae.

The Haversian canals run parallel with the long axis of the bone but branch and communicate at short intervals. They vary considerably in size, but their average diameter is about 0.05 mm. The canals near the medullary cavity are larger than those near the surface. Each canal usually contains a minute artery and vein, a small quantity of delicate areolar tissue, and some nerve-filaments; in the larger ones there are also lymph vessels, and cells with branching processes.

The trabeculae of the spongy substance and thin plates of bone consist of superimposed lamellae which receive their nutriment, not from blood vessels within their substance but from those in the tissues around them. Some large trabeculae, however, contain small Haversian systems.

On account of its regular lamellar arrangement normal adult bone is termed *lamellar bone*.

The *lamellae* are thin plates of bony tissue. This consists of a ground substance or *matrix*, in which are embedded fibres and which is impregnated with bone 'salts' which are mostly soluble in acids.

The matrix appears homogeneous; its composition has not been finally determined. When calcification of bone is incomplete as in rickets the uncalcified matrix is termed the *osteoid matrix*. Each Haversian and interstitial system of lamellae in adult bone is usually demarcated from neighbouring systems by a *cement line* which is strongly basiphilic and, unlike the remainder of the matrix, is devoid of collagen fibres (fig. 28).

The fibres in the matrix are believed to be identical with collagen fibres. There is some divergence of opinion concerning the arrangement of the fibres with successive lamellae. It is generally believed that in each lamella the fibres are arranged as sheets in which the individual fibres have the same general direction, which differs from the general direction of those in adjoining lamellae. Ruth* believes the fibres to be alternately compact and diffuse in successive lamellae, the former running circumferentially and the latter arranged radially. Gebhart,† on the other hand, believed the fibres to be arranged spirally, the pitch of the spiral differing in successive lamellae.

The circumferential lamellae are held together by tapering fibres, which spring

* Elbert B. Ruth, *Amer. J. Anat.*, 90, 1947.

† F. Gebhart, *Arch. f. Entw. u. Verw.*, 11 and 20, 1901 and 1906.

from the periosteum and run obliquely through them, pinning or bolting them together; these are termed the *perforating fibres* (of Sharpey) (fig. 29).

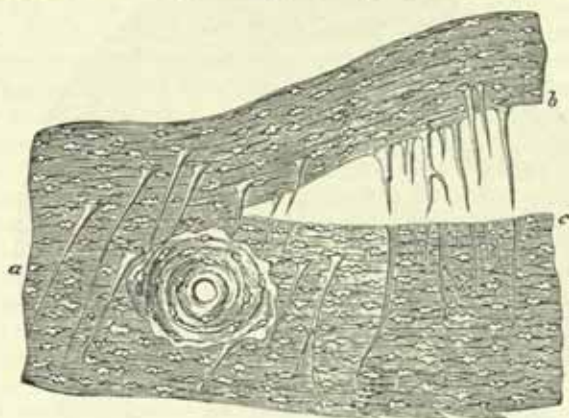
The *bone 'salts'* constitute the mineral constituents and confer on the bone its hardness and rigidity. The most important constituents of bone 'salts' are

FIG. 28.—A transverse section through the compact substance of the human femur of an elderly subject. Stained with orcein and picric acid. $\times 375$. Elbert B. Ruth. Reproduced by the courtesy of the author and the Editors of the *American Journal of Anatomy*.



calcium, magnesium, phosphate, carbonate, chloride, fluoride and citrate. The mineral substances of bone may be obtained by calcination, which destroys the organic matter. The bone retains its original form but is white and brittle, has lost about $\frac{1}{3}$ of its original weight and crumbles under the slightest force. On the other hand, the mineral constituents of bone are mostly soluble in mineral acids and may be removed by prolonged immersion in dilute solutions. The bone then retains its shape but is now perfectly flexible, so that a long bone (one of the ribs for example)

FIG. 29.—The perforating fibres of a human parietal bone, decalcified. (H. Müller.)
(From Quain's *Elements of Anatomy*, vol. ii, pt. i, Microscopic Anatomy.)



Perforating fibres *in situ*. *b*, Fibres drawn out of their sockets. *c*, Sockets.

can easily be tied in a knot. In a transverse section of such softened bone (fig. 27) the arrangement of the Haversian canals, lamellae, lacunae and canaliculi can be recognised.

The bone 'salts' are believed to consist of crystalline and amorphous components. The crystalline component consists of submicroscopic crystals disposed especially around the collagen fibres. Ionic exchanges occur readily at the surfaces of the

crystalline lattice where substances such as radium, strontium and fluorine may be rapidly substituted.*

The *lacunæ* are oblong spaces situated along the margins or in the middle of the compact lamellæ, and each lacuna is occupied during life by a branched *bone-cell* or *osteocyte*, the processes from which extend into the canaliculi.

The *canaliculi* are minute channels, crossing the lamellæ and connecting the lacunæ of a Haversian system with one another, and with the Haversian canal. The canaliculi at the periphery of a Haversian system do not as a rule communicate with those of neighbouring systems, but form loops and return to their own lacunæ. Thus every part of a Haversian system is supplied with nutrient fluids derived from the vessels in the Haversian canal and distributed through the canaliculi and lacunæ.

The *bone-cells* occupy, but do not fill, the lacunæ. They are flattened, nucleated branched cells, homologous with the fibroblasts of connective tissue. In the elderly they become greatly reduced in number.

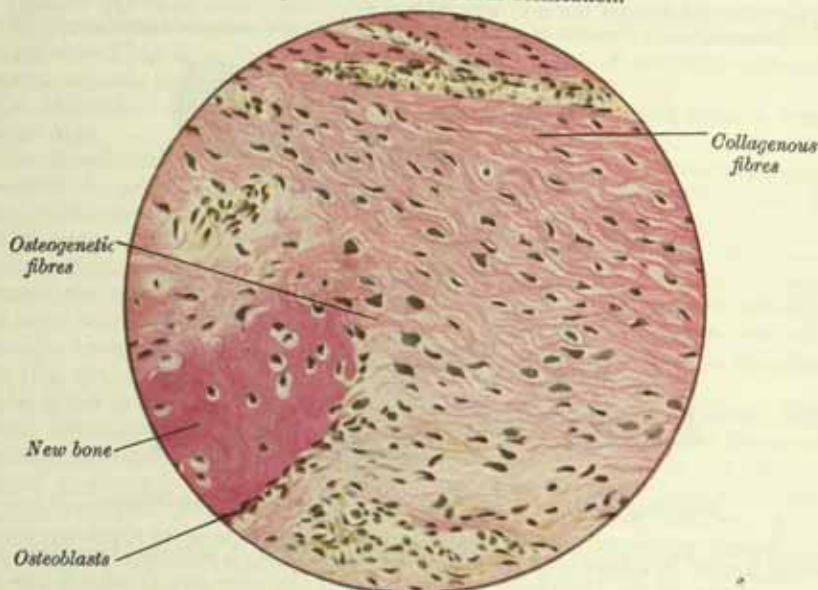
In thin plates of bone Haversian canals are absent.

Ossification.—Some bones, such as those of the roof and sides of the skull, are preceded by membrane, but most bones are preceded by rods or masses of cartilage. Hence two kinds of ossification are described; the *intramembranous* and the *intra-cartilaginous*; but there is no essential difference between these two methods of bone formation.

Intramembranous ossification.—The process of ossification of a bone begins at one or more, almost constant points known as *centres of ossification*. In intramembranous ossification a mesenchymal condensation occurs at this site, the cells proliferate, and the more centrally situated enlarge; their cytoplasm becomes more granular and basiphilic. A meshwork of collagenous fibres, termed *osteogenetic fibres*, appears between the cells. This is followed by the deposition of an amorphous basiphilic hyaline ground substance, which masks the fibres and incarcerates some of the cells. This is the osteoid matrix in which calcareous granules are deposited to form the calcified matrix of the bone. The imprisoned cells form the bone cells and the spaces in which they are enclosed constitute the lacunæ of the bone. At about the time of differentiation of the osteoblasts at the centre of ossification, the surrounding mesenchyme condenses to form the fibrous periosteum of the bone.

The extension of the ossification occurs through the agency of the osteoblasts remaining at the surface of the bone, which maintain themselves by mitotic activity

FIG. 30.—Intramembranous ossification.



and probably also by differentiation from the mesenchyme around. These cells progressively lay down new collagenous fibres, which radiate outwards from the

* For details see R. A. Robinson, *J. Bone and Joint Surg.*, 34A, 1952, and F. C. McClean and M. R. Urist, *Bone*, Chicago, 1955.

bone, and a hyaline matrix which is ultimately calcified (fig. 30). The bony trabeculae thus formed thicken by the addition of fresh layers formed by the osteoblasts on their surface and the meshes are correspondingly encroached upon. Subsequently the bone increases in thickness by the deposition of successive layers under the periosteum and round the larger vascular channels, which become the Haversian canals.

A layer of osteoblasts covers the surfaces where active bone formation is occurring. The intense basiphilia of their cytoplasm has been attributed to the presence of ribonucleic acid and related to the elaboration of the protein of the bone matrix. They also contain an appreciable amount of alkaline phosphatase and fine granules of a material which gives a positive periodic acid-Schiff reaction. These features are absent from mature cells.*

With the late growth of the part, for example the skull, there is much remodelling of the bones involving removal of bone at some surfaces and a further deposition of bone on other surfaces. The removal of bone is generally attributed to large multinucleated cells, with a finely granular basiphilic cytoplasm, termed *osteoclasts* or bone destroyers. These produce, possibly by enzymic action, localised erosions of the bone and can often be found in small pits termed *resorption lacunae* or *Haversian's lacunae* which they have hollowed out of the bone. The origin of the osteoclasts has been variously ascribed to undifferentiated cells in the bone marrow and to osteoblasts.

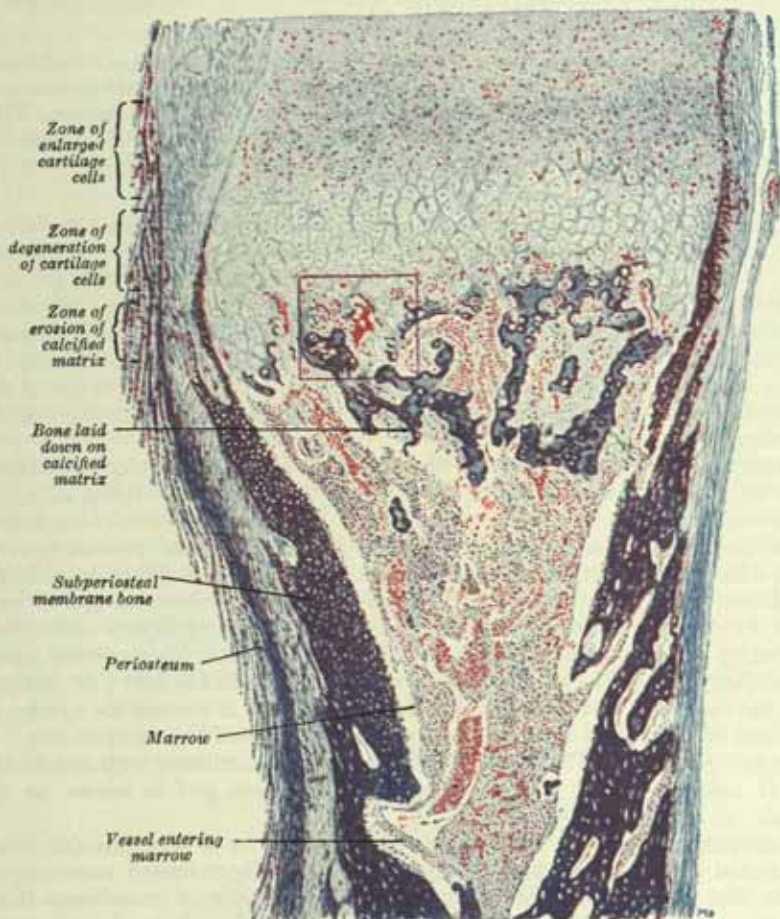
Intracartilaginous ossification.—Most of the bones are preformed in cartilage, and each long bone is represented in early foetal life by a rod of hyaline cartilage, which replaces a rod of condensed mesenchyme. The *primary centre of ossification* appears in the centre of the rod and the process of bone formation extends towards the ends, which remain cartilaginous for a length of time which differs for different bones. Later, ossification begins at one or more *secondary centres* in one or both ends and the portions of bone formed from them constitute *epiphyses*. Most long bones develop an epiphysis at each extremity, but in some (metacarpals, metatarsals, phalanges and ribs) an epiphysis is formed at one end only. The cartilage between the epiphysis and the growing shaft or *diaphysis* is termed the *epiphyseal cartilage* and its peripheral margin constitutes the *epiphyseal line* on the surface of young bones (fig. 419). The part of the diaphysis immediately adjacent to the epiphyseal cartilage is the site of advancing ossification and is known as the *metaphysis*. It is particularly vascular.

The cartilaginous model of the bone is surrounded by a very vascular membrane, termed the *perichondrium*, which is formed by condensed mesenchyme similar to that already described as constituting the basis of membrane bone. Between this membrane and the underlying cartilage there is a layer of osteogenetic mesenchyme, from which the formative-cells (the *osteoblasts*) are derived. Prior to the appearance of the primary centre of ossification the cartilage-cells in the middle of the shaft become greatly enlarged and the trabeculae between them become reduced to thin partitions. The cartilage-cells, possibly owing to autointoxication due to absorption of the surrounding matrix during the period of growth, undergo degenerative changes and die. Their bodies become shrunken and leave spaces which are termed the *primary areolae*. Subsequent to the death of their parent cells the thin partitions between these spaces become calcified. The weakening of the shaft brought about in this way is compensated for by the subperichondral osteoblasts, which lay down a peripheral fenestrated layer of young bone by the intramembranous method previously described. These changes constitute the first stage in the process of intracartilaginous ossification.

The second stage consists in the prolongation into the cartilage of processes of the deeper or osteogenetic layer of the perichondrium (now periosteum). The processes consist of blood-vessels and cells—osteoblasts and osteoclasts. The latter excavate passages through the new-formed bony layer by absorption, and pass through it into the calcified matrix. Wherever these processes of the osteogenetic layer come in contact with the calcified walls of the primary areolae they absorb them, and thus cause a fusion of the original cavities and the formation of larger spaces, which are termed the *secondary areolae* or *medullary spaces*. These secondary spaces are filled with embryonic marrow, consisting of osteoblasts and

vessels, derived, in the manner described above, from the osteogenetic layer of the periosteum (fig. 31).

FIG. 31.—A longitudinal section through a metatarsal bone of a fetal rat. Mallory's stain.



The walls of the secondary areolæ increase in thickness by the deposition of layers of bone on their surface. This process takes place in the following manner. Some of the osteoblasts of the embryonic marrow, after undergoing rapid division, arrange themselves as a layer on the surface of the wall of the space (fig. 31). This layer of osteoblasts forms a bony stratum, which gradually covers the wall of the space and in which some of the osteoblasts are included as bone-cells. The next stage in the process consists in the removal of these primary bone-spicules by the osteoclasts (fig. 32). This process goes on *pari passu* with the formation of permanent bone by the osteogenetic layer of the periosteum, and in this way the medullary cavity of the bone is formed.

While bone is being laid down in the middle of the shaft the adjoining cartilage reacts in a manner which prepares it for the extension of the ossifying process. In the area directed towards the end where an epiphysis appears later, the cartilage cells undergo rapid division, at first in the transverse axis of the bone and then in its long axis, so as to give rise to a great number of parallel rows of disc-shaped cells, marking the *zone of proliferation*. This process goes on throughout the period of growth and is responsible for increase in length of long bones.* The older cells, which lie nearest to the primary centre of ossification, become hypertrophied and this enlargement is associated with the intracellular storage of glycogen.† These cells mark the *zone of hypertrophic cartilage*. Most, if not all, of these distended cells die,

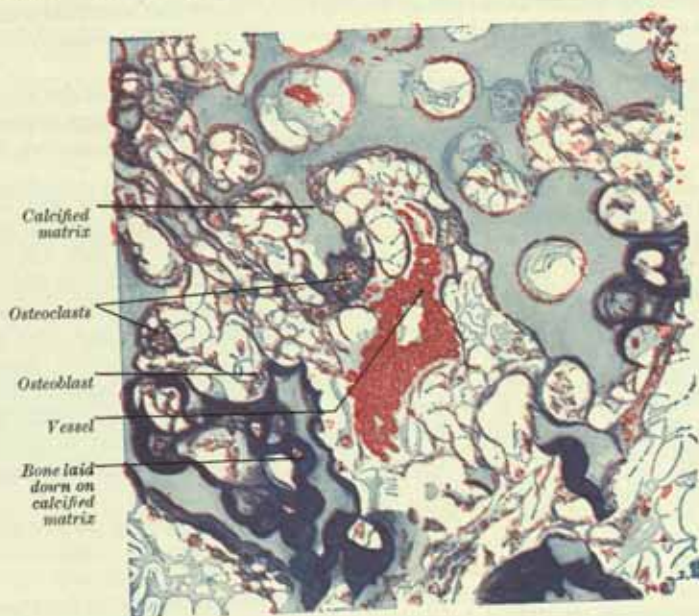
* C. W. Stump, *J. Anat., Lond.*, 59, 1925.

† H. A. Harris, *Bone Growth in Health and Disease*, 1933.

the trabeculae between the columns undergoing calcification to form the *zone of calcified cartilage*. Osteoclasts and osteoblasts from the primary centre extend the process of ossification in the longitudinal direction by invading the columns, removing the trabeculae and laying down new bone. As ossification extends along the shaft, the cartilage-cells at the epiphyseal end of the rows divide rapidly, while those at the opposite end progressively hypertrophy and atrophy (fig. 31).

The cells and matrix in the zone of hypertrophic cartilage and the osteoblasts are rich in the enzyme, alkaline phosphatase, which is believed to be ultimately concerned with the formation of the osteoid matrix and particularly of the fibres within it.

FIG. 32.—A part of fig. 31 (enclosed within the square) more highly magnified.



This series of changes proceeds gradually towards the ends of the bone, so that all the changes described above may be seen in different parts, from the true bone at the centre of the shaft to the hyaline cartilage at the extremities.

While the ossification of the cartilaginous shaft is extending towards the articular ends, the epiphyseal cartilage immediately in advance of the bony tissue continues to grow until the length of the adult bone is reached. At the same time the formation of periosteal bone advances towards the ends of the shaft and by surface deposition leads to an increase in the thickness of the bone.

One or more secondary bony centres appear in the cartilaginous extremities and initiate in them the process of ossification; but the ends remain separated from the shaft of the bone by the epiphyseal cartilages for a definite time. Ossification of epiphyses and ossification of the diaphysis in the direction of an extremity where no epiphysis develops (e.g. the distal ends of the phalanges, etc.) are not marked, in the earliest stages, by the preliminary formation of rows of cells.* Instead, the cartilage-cells constitute small groups or cell-nests, which undergo hypertrophy and, later, die, a change accompanied by calcification of the surrounding matrix. These groups become invaded by osteoblasts and osteoclasts and bone is laid down in the manner already described. Hurrell † regards the ingrowth of vascular canals as an essential preliminary and, in his view, the embryonic connective tissue which they contain gives rise to the osteoblasts in question. The epiphyseal cartilages ultimately ossify and the bone assumes its completed form and shape. The same remark applies to such processes of bone as are ossified from separate epiphyses, e.g. the trochanters of the femur.

* G. S. Dodds, *Anat. Rec.*, 46, 1930 and cf. H. A. Harris, *loc. cit.*

† D. J. Hurrell, *J. Anat., Lond.*, 69, 1934.

Bones increase in length by ossification continuing to extend into the epiphyseal cartilages, which go on growing in advance of the ossifying process; when the growth of the epiphyseal cartilages ceases, the diaphysis and the epiphyses unite. Bones increase in circumference by deposition of new bone from the osteogenetic layer on their sub-periosteal aspects, and at the same time an absorption takes place from within, by which the medullary cavities are increased. It should be observed that, in certain situations, e.g. the ramus of the mandible (p. 309) and the expanded extremities of the shafts of the long bones, a process of remodelling is necessary during the stage of lengthening, in order that the outline of the bone may remain constant throughout the period of growth.* This remodelling is brought about by a process of absorption, which goes on side by side with the process of deposition and is an essential feature of normal growth in the situations cited.

The bone first laid down is spongy in structure. Later the osteoblasts contained in its spaces form the concentric layers characteristic of the Haversian systems, and are included as bone-cells.

The number of ossific centres varies in different bones. Most of the short bones are ossified from a single centre. In each long bone there is a primary centre for the shaft, or diaphysis; and one or more secondary or epiphyseal centres for each extremity. That for the shaft is the first to appear.

The times of union of the epiphyses with the shaft vary inversely with the dates at which their ossifications begin (with the exception of the fibula) and are related to the direction of the nutrient arteries of the bones in man. Thus, the nutrient arteries of the bones of the arm and forearm are directed towards the elbow, since the epiphyses at this joint become united with the shafts of the bones before those at the opposite extremities. In the lower limb, on the contrary, the nutrient arteries are directed away from the knee; that is, upwards in the femur, downwards in the tibia and fibula; and in them it is observed that the epiphyses at the upper end of the femur, and those at the lower ends of the tibia and fibula, unite first with the shafts. Where there is only one epiphysis, the nutrient artery is directed towards the other end of the bone. The growing end of the macerated diaphysis has a curious coral-like appearance, which is quite characteristic.

Increase in length of the long bones occurs in all vertebrates by proliferation and ossification of the cartilaginous ends. Secondary centres of ossification occur constantly in mammals but only sporadically in other vertebrates.† There is, however, some reason to believe that they were present in the extinct group of mammal-like reptiles.‡ Their presence at the expanded ends of the long bones reduces very considerably the amount of remodelling by absorption which would be necessary, if they did not develop. Parsons§ grouped epiphyses under three headings, viz. (1) *pressure epiphyses*, appearing at the articular ends of the bones and transmitting 'the weight of the body from bone to bone'; (2) *traction epiphyses*, associated with the insertion of muscles, and 'originally sesamoid structures though not necessarily sesamoid bones'; and (3) *atavistic epiphyses*, representing parts of the skeleton which at one time formed separate bones, but which have lost their function 'and only appear as separate ossifications in early life'. It should be stated, with reference to traction epiphyses, that Appleton|| found that their development was not arrested by section of the tendon concerned prior to their time of appearance.

Applied Anatomy.—Many of the periosteal vessels reach the periosteum through the attachments of the muscles, so that when the latter are well-developed and their blood-supply abundant the periosteum is also well supplied with blood and the bones are strongly developed with prominent ridges. Conversely if the muscular development is poor the bones are thin and light. This is strikingly demonstrated in cases of infantile paralysis where several muscles of a limb become paralysed at an early period of childhood. The periosteal blood-supply suffers and consequently very little fresh osseous tissue is added to the outer surfaces of the bones. In such cases although the limb continues to grow in length at the epiphyseal cartilages, its length is less than

* A. Keith, *J. Anat. Lond.*, 54, 1919-20.

† R. W. Haines, *J. Anat. Lond.*, 72, 138, 1937.

‡ R. Broom, *Origin of the Human Skeleton*, 1930.

§ F. G. Parsons, *J. Anat. and Physiol.*, 38, 1904, 39, 1905, and 42, 1908.

|| A. B. Appleton, *J. Anat. Lond.*, 62, 1922.

that of the normal side ; but the most striking feature of the bones is their extreme thinness.

Since increase in the length of a bone depends on continued growth at the epiphyseal cartilages, it is necessary that great care should be taken not to interfere with these in dealing with disease in the neighbourhood of an epiphysis. A knowledge of the periods when the epiphyses join the diaphyses is often of importance in medico-legal enquiries. It is also of practical utility in deciding the nature of an injury in the neighbourhood of a joint, since separation of an epiphysis may simulate a fracture or a dislocation. Further, when amputation through one of the long bones is called for in a young subject the activity of growth at the epiphyseal cartilage must be borne in mind. As special cases, amputation through the humerus or tibia may be cited, since in these bones the proximal epiphyses are late in joining the diaphyses. If sufficient allowance be not made for this by cutting long flaps, the portion of the diaphysis remaining will continue to grow till its distal end projects through the stump—a condition known as *conical stump*.

As the shaft of a long bone increases in length normally there must be a continual remodelling at the surface in the metaphyseal region. When this fails to occur the extremities of the shaft are irregularly thickened and the condition is termed *diaphysal aclasis*. This condition is also attributed to a failure of the ferrule of periosteal bone to restrict the growth in girth of this region.

Metabolic factors affecting the growth of bone.*—To ensure the normal development and maintenance of bone, there must be an adequate intake of calcium and phosphorus compounds and, further, the diet must contain a sufficiency of vitamin D. Vitamin D influences the absorption of calcium and indirectly of phosphorus compounds from the intestine and thus indirectly their proportions in the blood stream. It probably also influences the deposition of bone salts. Deficiency of vitamin D in the diet during the growth period leads to the condition of rickets, in which the process of ossification on the diaphyseal side of the epiphyseal cartilage is seriously upset. The calcification of the cartilage is irregular, the bone formed is imperfectly ossified, and deformities may result from normal stresses.

In addition to providing skeletal support, bones form an important reserve of calcium and phosphorus in the body. The level of the blood calcium is markedly influenced by the hormone secreted by the parathyroid glands which is believed to stimulate the osteoclastic resorption of bone.

Severe illnesses, occurring during the period of active growth of the long bones, cause a temporary arrest of growth which can be recognised later in radiographs as a dense line of bony deposition. This is succeeded by a zone of renewed growth in which it may be possible to detect that the bone laid down during convalescence was poorly differentiated.†

Bony overgrowth may be due to a number of different factors. Hypersecretion by the eosinophil cells of the anterior part of the hypophysis cerebri leads to the condition of acromegaly (p. 1013). Castration during the growth period leads to a delay in the union of the epiphyses and so to overgrowth. Again, it has been shown experimentally that a diet deficient in vitamin A is associated with an overgrowth of the bones of the base of the skull, manifested especially by encroachment on the size of the foramina.

Premature arrest of growth of the epiphyseal cartilages results in too early junction of the epiphyses with the diaphyses (*premature synostosis*). This brings to an end the growth in length of the bones, and is one of the causes of dwarfism. Persons in whom this has occurred will have the head and trunk of normal size, but the legs and arms disproportionately short though often very strong.

MUSCULAR TISSUE

Muscular tissue is composed of bundles of reddish fibres endowed with the property of contractility. There are three varieties of muscle, (1) *striped or voluntary*, (2) *unstriped or involuntary*, and (3) *cardiac*. The muscles which are concerned with the movements of the bony skeleton—the skeletal muscles—are composed of striped fibres, and are under the control of the will. The muscular coats of the stomach and intestines, uterus, bladder and blood-vessels, on the other hand, are formed of unstriped fibres, and their movements are involuntary. Some striped muscles, however, are not under voluntary control, namely, those forming the walls of the pharynx and upper part of the œsophagus. Cardiac muscle is intermediate in

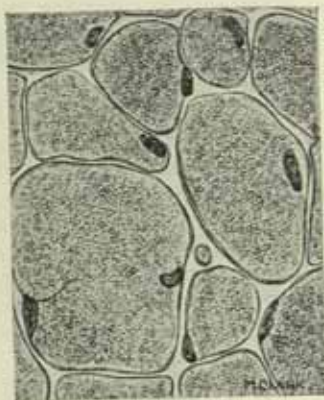
* E. Mellanby, *Journal of Physiology*, 94, 1938.

† H. A. Harris, *loc. cit.*

position between the other two varieties. Its fibres are striped, but involuntary, and they differ from both striped and unstriped muscle in structure. With the exception of the *arrectores pilorum* and the sphincter and dilator pupillae muscles, which are derived from the ectoderm, all muscle tissue is mesodermal in origin.

The **striped muscular fibres** are arranged in bundles or *fasciculi*, in which the individual fibres are parallel to one another. Each fasciculus has a connective tissue sheath, called the *perimysium*, prolongations of which run into the bundle, binding the fibres together and constituting the *endomysium*. A muscle is composed of a number of fasciculi, held together and surrounded by connective tissue which

FIG. 33.—A transverse section through human striped muscle-fibres. $\times 255$.



known as the *epimysium*. The fasciculi are of different sizes in different muscles, and are for the most part placed parallel with one another, though they usually converge towards the tendinous attachments. The connective tissue framework of the muscle contains the blood-vessels and nerves which supply it.

A *muscular fibre* consists of a soft contractile substance, enclosed in a tubular sheath called the *sarcolemma*. The fibres are cylindrical or prismatic in shape (fig. 33), and their length varies from a few mm. in short muscles such as the tensor tympani to more than 30 cm. in long muscles such as the sartorius.* Their breadth varies in man from 0.01 mm. to 0.1 mm. As a rule, the fibres do not divide or anastomose; but occasionally, especially in the tongue and facial muscles, they may be seen to divide into several branches. The fibres taper at both ends and these are joined, the one to the tendon of origin and the other to the tendon of insertion. In long

fasciculi the fibres may terminate without joining the tendon directly. Where a muscle joins its tendon, the sarcolemma covering the end of each muscle-fibre blends with a corresponding group of the fine fibres of the tendon. The muscular substance of the fibre can readily be made to retract from the point of junction. The areolar tissue between the fibres is prolonged into the tendon, so as to form a kind of sheath around the tendon-bundles for a longer or shorter distance. When muscular fibres are attached to skin or mucous membranes, this sheath becomes continuous with the areolar tissue of these structures.

FIG. 34.—Striped muscle fibres (human) from the sternothyroid muscle. Drawn from a photomicrograph.



The *sarcolemma*, or tubular sheath of the fibre, is a transparent, elastic, and apparently homogeneous membrane of considerable toughness, so that it sometimes remains intact when the included substance is ruptured. It is a very fine membrane, exceedingly difficult to demonstrate by the ordinary staining methods. Not infrequently the term sarcolemma is applied to the endomysium which clothes it. On the internal surface of the sarcolemma in mammalia, and also in the substance of the fibre in frogs, elongated nuclei are seen, and each of these is surrounded by a little granular protoplasm. The fibres are multinucleated and may represent a syncytium.†

Upon examination by transmitted light, a voluntary muscle fibre is found to be marked by alternate light or *I* bands and dark or *Q* bands or *striæ*, which pass transversely across it (figs. 34, 35). When examined by polarised light the *Q* bands are found to be doubly refract-

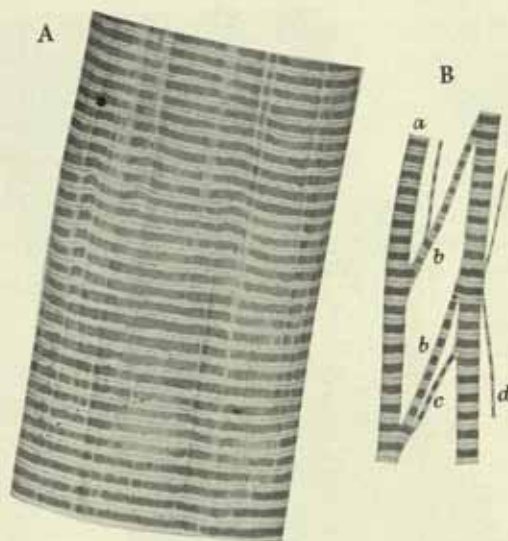
ing (anisotropic), while the *I* bands are singly refracting (isotropic). The *Q* and *J*

* R. D. Lockhart and W. Brandt, *J. Anat., Lond.*, 72, 1937-38.

† W. E. Le Gros Clark, *The Tissues of the Body*, Oxford Univ. Press, 1939.

bands are of nearly equal breadth, and alternate with great regularity; they vary in breadth from about 1μ to 2μ . When the fibre is focussed deeply a dark line may be seen running in the middle of the J band. This is known as the *Z disc*

FIG. 35.—A. A portion of a medium-sized human muscular fibre. Magnified nearly 800 diameters. B. Separated bundles of fibrils, equally magnified. (From Quain's *Elements of Anatomy*.)



a. Larger, and b, b, smaller collections. c. Still smaller. d. The smallest which could be detached.

(Krause's membrane). In fibres that are on the stretch the Q band is seen to be divided by a clearer line—Hensen's line, within which is a thin middle stripe, the *M line*. The segment of the muscle fibre included between successive *Z discs* is known as a *sarcomere*.

Under high magnification striped muscle fibres are seen to be composed of a large number of fibrils, the *myofibrils* or *sarcostyles*, embedded in an interfibrillar material, the *sarcoplasm* (figs. 34, 35, 36). The myofibrils are arranged in groups called muscle columns, the groups being separated by a larger amount of sarcoplasm than the separate fibrils. In transverse section the muscle columns defined in this way constitute what are known as *Cohnheim's areas*. Under the electron microscope the myofibrils can be seen to consist of large numbers of fine filaments, the *myofilaments*, each measuring about 150 \AA in diameter. Scattered through the sarcoplasm are minute granular elements, the *sarcosomes*. These have the characteristics of mitochondria. Also visible in the sarcoplasm with the electron microscope is the *sarcoplasmic reticulum*.

There is, as yet, no unanimity of opinion concerning the structural basis or significance of the striations in striped muscle. Sir E. Sharpey-Schafer's theory that the Q band contains a number of longitudinal channels opening towards the *Z disc* and closed at the line of Hensen cannot be substantiated. According to his view the substance of the J band passed into these channels during contraction. Nor does Carey's * view that the striations represent a system of pressure waves meet with general acceptance. Carey and others † maintain that the number of striations in the living muscle of the freshwater shrimp increases with temperature. These authors maintain that the sarcomere cannot be regarded as the structural unit of striped muscle. While confirming the presence of striations electron microscopy has so far added little to the clarification of the problem. It would appear, however, that the myofilaments may be continuous through several sarcomeres and that the fibrous protein composing the filaments is the same in both J and Q bands. There is evidence that constituents other than the fibrous protein of the muscle may be responsible for the differing physical properties of the J and Q bands. When pressed on a film of soft collodion, a muscle fibre leaves an imprint which reproduces the appearance of transverse striations. Tudor Jones has

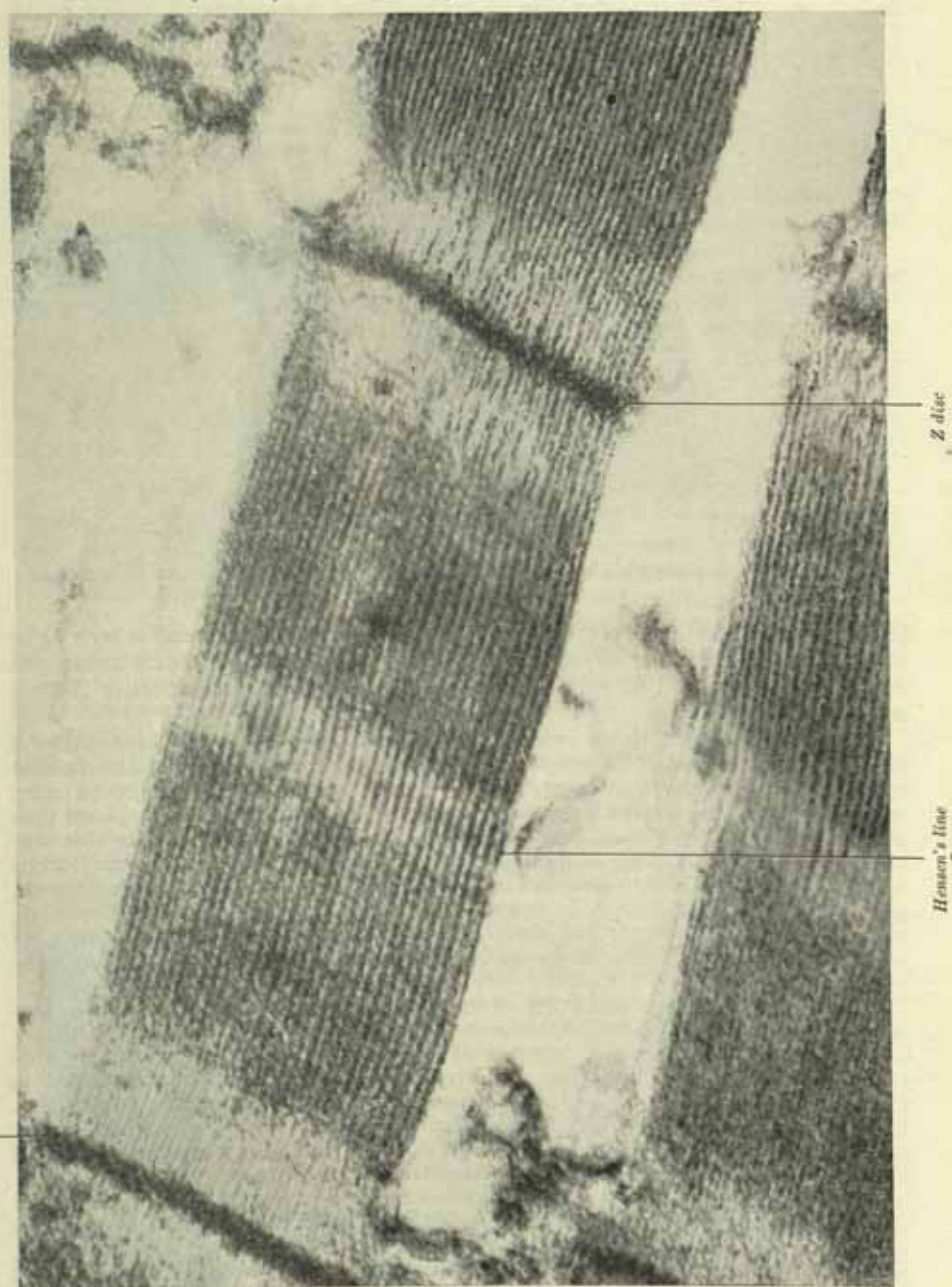
* E. J. Carey, *Amer. J. Anat.*, 58 and 59, 1936, and 61, 1937.

† E. J. Carey, W. Zeit and L. Massopust, *Amer. J. Anat.*, 70, 1942.

demonstrated that the striations on the imprint react to polarised light in precisely the same way as muscle striations themselves. It would appear that the basis of muscular contraction is to be sought at the macro-molecular level.*

FIG. 36.—Electron micrograph of a longitudinal section of a sarcomere. $\times 86,800$. Fixed in 1% buffered osmium tetroxide, treated with phosphotungstic acid and embedded in methocrylate.

Prepared by Miss J. Hanson and Mr. H. E. Huxley; reproduced by permission of the Society for Experimental Biology from Symposium No. IX.



Vessels and nerves of striped muscle.—The *capillaries* of striped muscle are very abundant, and form a sort of rectangular network, the branches of which run longitudinally in the endomysium between the muscular fibres, and are joined at short intervals by transverse anastomosing branches. In the red muscles of the rabbit dilatations occur on the transverse branches of the capillary

* W. T. Astbury, *Proc. Roy. Soc. B.*, 134, 1947.

network. The larger vascular channels (arteries and veins) are found only in the perimysium, between the muscular fasciculi. *Nerves* are profusely distributed to striped muscle. Their mode of termination is described in the chapter on *Neurology*. *Lymph vessels* are not present in striped muscle, though they have been found in tendons and in the sheaths of the muscles.

According to John Irvine Hunter, vertebrate muscle, like that of the invertebrates, consists of two kinds of fibres, i.e. those connected with active contraction, and those responsible for the maintenance of tonic contraction. The former are the ordinary striped muscle fibres innervated by ordinary medullated motor fibres. The latter consist of thin, red fibres, rich in sarcoplasm, with central nuclei and with a non-medullated sympathetic nerve-supply. Though adequate proof has been adduced for the double innervation of striped muscle, no unequivocal experimental evidence has been advanced in favour of the regulation of muscle-tone by sympathetic nerves.

Repair of voluntary muscle.—Although it has commonly been stated that damaged muscle tissue is replaced normally by fibrous tissue, it has recently been demonstrated by the experimental method* that when voluntary muscle suffers serious injury the part destroyed is replaced by the growth of new fibres from both ends of the damaged fibres. Histiocytes play an important part in removing necrosed tissue and fibroblasts are responsible for the reconstitution of the endomysial and sarcolemmal sheaths into which the new fibres grow. The formation of new fibres is a relatively rapid process and cross-striation can be recognised three weeks after the lesion has been inflicted.

Unstriped, plain, or involuntary muscle is found in the following situations—in the lower half of the œsophagus and the whole of the remainder of the gastrointestinal tube; in the trachea and bronchi; in the gall-bladder and bile-duct; in the large ducts of the salivary and pancreatic glands; in the calyces of the kidney, the ureter, including its pelvis, the bladder, and urethra; in the female sexual organs—viz. the ovary, the uterine tube, the uterus (enormously developed in pregnancy), the vagina, the broad ligament, and the corpora cavernosa of the clitoris; in the male sexual organs—viz. the dartos of the scrotum, the vas deferens and epididymis, the seminal vesicle, the prostate and the corpora cavernosa and corpus spongiosum of the penis; in the capsule and trabeculae of the spleen; in the mucous membranes, forming the muscularis mucosæ; in the skin, forming the arrectores pilorum, and also in the sweat-glands; in the mammary glands; in the arteries, veins, and lymph vessels; in the iris and ciliary muscle.

Unstriped or plain muscle is made up of spindle-shaped cells (fig. 37), collected into bundles and held together by a cement-substance. These bundles are further aggregated into larger fasciculi, or sheets, bound together by areolar tissue.

The cells are elongated, spindle-shaped, and are of various sizes, averaging from 40μ to 80μ in length, and 6μ to 7μ in breadth. On transverse sections they are more or less polyhedral in shape, from mutual pressure. Each consists of contractile substance enclosed in an elastic cell wall and contains an oval or rod-like nucleus. In the living cell the cytoplasm appears homogeneous but after fixation it presents a faint longitudinal striation due to the presence of myofibrils, which are embedded in an interfibrillar substance or sarcoplasm. The myofibrils are not transversely

FIG. 37.—Muscle fibres from the small intestine. (Quain's *Elements of Anatomy*, 10th Edition.)



A. A complete cell. B. A damaged cell, showing the torn cell-wall and the deeply-staining pyknotic nucleus.

striated. A centriole lies close to the nucleus. The fibres are attached to one another by a certain amount of interstitial cement-substance which reduces nitrate

FIG. 38.—Anastomosing muscular fibres of the heart seen in a longitudinal section. On the right the limits of the separate cells with their nuclei are exhibited somewhat diagrammatically. (Schweigger-Seidel.)

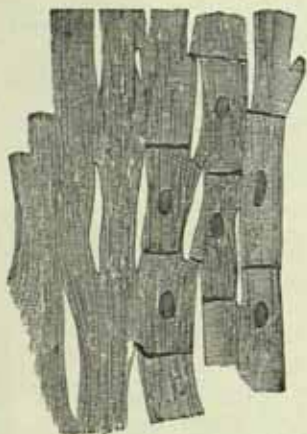
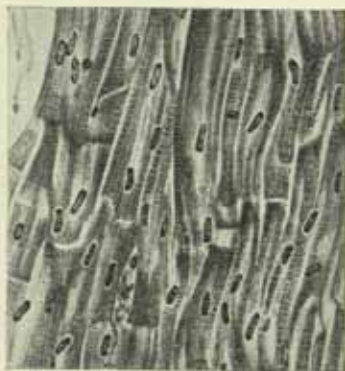


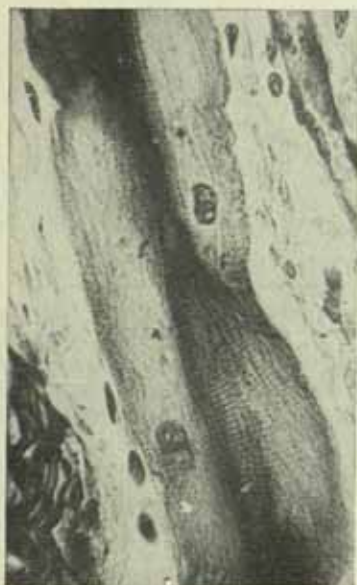
FIG. 39.—Cardiac muscle, human. Drawn from a photomicrograph.



of silver, and by a network of reticular and elastic fibres, but in some regions, e.g. the muscular coat of the intestines, the muscle-cells are also connected by 'bridges' similar to those described in the prickly cells of the epidermis.

The response of plain muscle to nervous stimulation, although sluggish, may be sustained. Even in the absence of nervous stimuli sheets of smooth muscle frequently exhibit rhythmical contractions,

FIG. 40.—Purkinje's fibres from the sheep's heart, in longitudinal section. $\times 250$. Photomicrograph kindly lent by Professor Francis Davies.



which in many cases travel along the sheet in the form of waves. Such waves are well marked in the wall of the intestine. Contraction is often excited by a mechanical stimulus; for example, distension of the urinary bladder or of the rectum excites the appropriate reflex of evacuation.

Cardiac muscular tissue.—The muscle fibres of the heart are striated both transversely and longitudinally, but the striation is finer as compared with that of striped muscle. The tissue consists of a branched syncytium. At intervals along the fibres are deeply staining transverse bands termed *intercalated discs* (fig. 38) variously interpreted as cell boundaries, irreversible contraction bands, fragmentation artefacts or growth centres. The myofibrils of heart muscle resemble closely those of striped skeletal muscle, in respect of the number, character and positions of the transverse striations. The nuclei, which are oval in outline and central in position (fig. 39), occur at regular intervals. The connective tissue between the bundles of fibres is much less than in ordinary striped muscle, and no sarcolemma has been proved to exist.

Purkinje's fibres (fig. 40).—Between the endocardium and the ordinary cardiac muscle peculiar fibres known as *Purkinje's fibres* are found embedded in a small amount of connective tissue. They

are associated with the terminal distributions of the atrioventricular bundle. In man the fibres are no larger in size than the cardiac cells but differ from them in several ways. In longitudinal section they are quadrilateral in shape, being about twice as long as they are broad. The central portion of each fibre contains one or more nuclei and is made up of granular protoplasm, with no indication of striation, while elsewhere in the fibre transverse striations are conspicuous (fig. 40). The fibres branch and are intimately connected with each other, but possess no definite sarcolemma.

The **atrioventricular bundle** (see section on Blood Vascular System) is composed of cells which differ from ordinary cardiac muscle-cells in being more spindle-shaped. They are, moreover, more loosely arranged and have a richer vascular supply than the rest of the cardiac muscle.

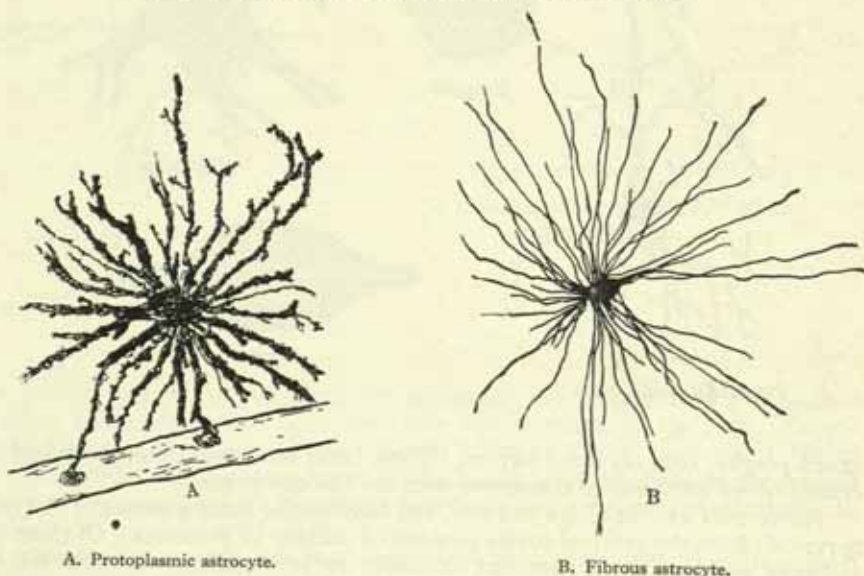
NERVOUS TISSUE

Nervous tissue is specialised for the initiation, propagation and reception of nerve impulses, and its high degree of specialisation is indicated by the fact that it has lost the power of reproduction. The nervous tissues of the body comprise the brain, the spinal medulla, the cranial, spinal, and autonomic nerves, and the ganglia connected with them.

The nervous tissues are composed of *nerve-cells* and their various processes, together with a supporting tissue called *neuroglia*, which, however, is found only in the brain and spinal medulla. Certain long processes of the nerve-cells are of special importance, and it is convenient to consider them apart from the cells; they are known as *axons* or *axis-cylinder processes*, and together with their covering sheaths they form the *nerve-fibres*.

To the naked eye certain portions of the brain and spinal medulla appear grey and others white, when freshly cut sections are examined. The *grey matter* is composed largely of nerve-cells, while the *white matter* contains only their long processes, the nerve-fibres. It is in the former that nervous impressions are received, stored, and transformed into efferent impulses, and by the latter that they are conducted. Hence the grey matter forms the essential constituent of all the nerve centres, both

FIG. 41.—Neuroglia-cells of the brain shown by Golgi's method. (After Andriezen.)
(From Sir E. Sharpey-Schafer's *Essentials of Histology*.)



A. Protoplasmic astrocyte.

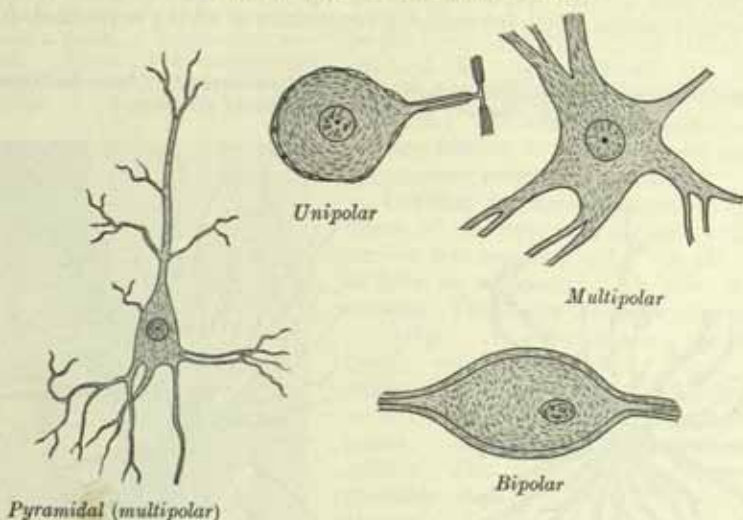
B. Fibrous astrocyte.

those in the isolated ganglia and those aggregated in the brain and spinal medulla; while the white matter forms the peripheral nerves and the bulk of the rest of the brain and spinal medulla.

Neuroglia and its constituent cells are of several varieties. *Astrocytes* are stellate cells with numerous processes; there are two types. Protoplasmic astrocytes (fig. 41 A) are found in grey matter and have numerous elaborately branched processes. Fibrous astrocytes (fig. 41 B) have small ill-defined cell bodies, with fine, elongated processes, which constitute neuroglia fibres; they are found principally in white matter. Astrocytes have a close relation to the capillaries and some of their processes end in flattened expansions on the vessel wall (fig. 41a). *Oligodendroglial cells* are small and tend to be closely associated with nerve-cells, while their processes, which are less numerous than those of astrocytes, group themselves along nerve-fibres. It has been suggested that they function as the neurolemma of the nerve-fibres of the central nervous system. *Microglial cells*, found mainly in grey matter, have fewer processes but are amœboid and phagocytic. Like the cells of the reticulo-endothelial system (p. 53) they are capable of taking up vital dyes such as trypan blue. They appear at a later stage of development than the other neuroglial elements and are first identified immediately under the pia mater. Later they penetrate into the grey matter. For these reasons they are generally regarded as being mesodermal in origin. In addition, *ependymal cells* (p. 933) send out processes from their outer ends to form neuroglial fibres. It would appear that, with the exception of microglial cells, which are mesodermal in origin and accompany invading blood-vessels into the developing central nervous system, all other types of neuroglial cells are derived from the ectoderm through the spongioblasts (p. 125). The fibres of neuroglial cells form a supporting meshwork for the delicate tissue of the nervous system, and neuroglia itself therefore functions as a true connective tissue despite its peculiar mode of development. It is condensed to form a thin layer on the surface of the brain and spinal medulla immediately under the pia mater, and a similar layer at the ependymal lining of the ventricles and the central canal of the spinal medulla.

Nerve-cells (fig. 42) are largely aggregated in the grey substance of the brain and spinal medulla, but smaller collections of these cells also form the swellings,

FIG. 42.—Various forms of nerve cells.



called *ganglia*, seen on many nerves. These latter are found upon the spinal and cranial nerve-roots and in connexion with the autonomic nerves.

Nerve-cells vary in shape and size, and have one or more processes. A typical nerve-cell from the cerebral cortex possesses a number of processes. "Of these one, and only one, acts as a transmitter to convey nerve impulses away from the cell. It is termed the *axon*, and it has a characteristic structure, to be described later. The other processes are all receptors, and convey nerve impulses to the cell; they are termed *dendrites* and they differ from the axon in structure as well as in other ways. Usually the axon is a long process, which gives off one or two collaterals

(fig. 43) but does not branch freely until it approaches its termination. The dendrites, on the other hand, are usually short and are restricted to the immediate vicinity of the cell-body. They branch freely, sometimes producing the most intricate patterns (fig. 44), and end in minute twigs. Such nerve-cells are termed *multipolar*, and they abound in the grey matter of the brain and spinal medulla and in the ganglia of the sympathetic system.

All nerve-cells, however, are not multipolar. The nerve-cells in the retina and in the spiral and vestibular ganglia of the eighth cranial nerve are *bi-polar* (fig. 42).

FIG. 43.—A pyramidal cell from the cerebral cortex of a mouse. Golgi method. (After Ramón y Cajal.)

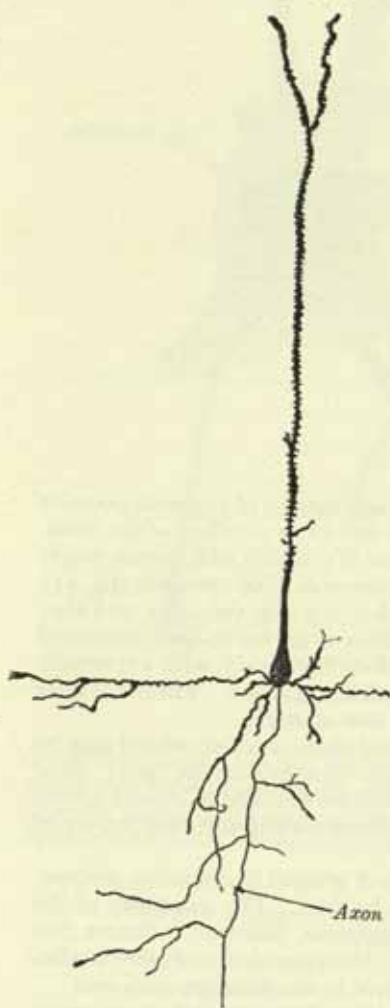
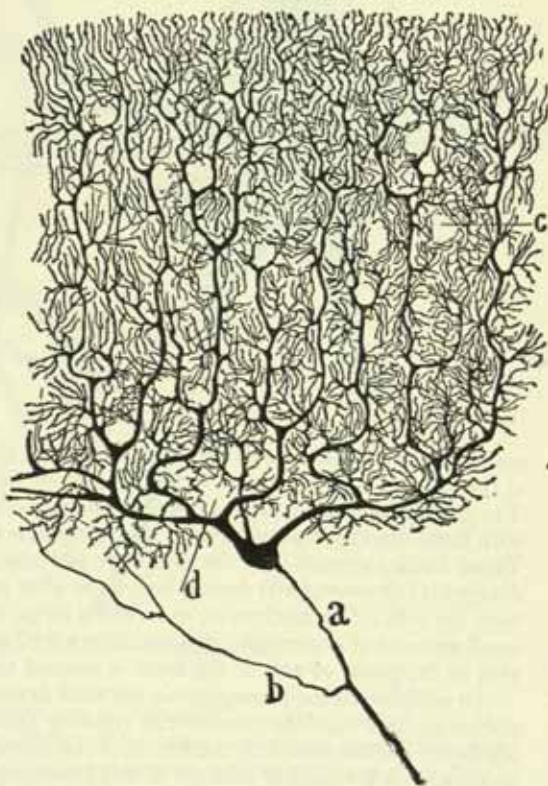


FIG. 44.—A cell of Purkinje from the cerebellum. Golgi method. (Ramón y Cajal.)



a. Axon. b. Collateral. c and d, Dendrites.

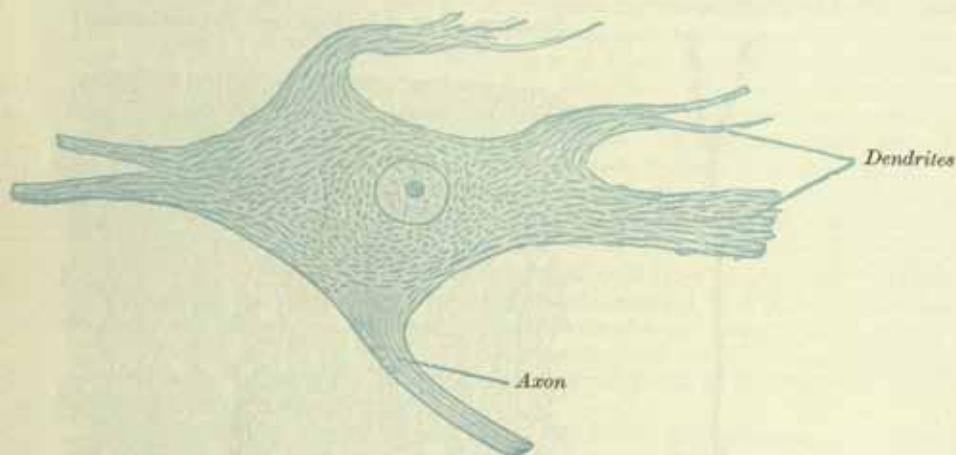
One process enters the cell from the periphery and functions as a dendrite: the other leaves the cell to enter the brain and functions as the axon. Structurally, however, both are axons. Bipolar cells are found throughout life in the spinal ganglia of fishes, and they occur in the same situation in the human embryo. The condition of bi-polarity therefore may be regarded justifiably as primitive.

In the adult the nerve-cells in the spinal ganglia and the ganglia of the cranial nerves (apart from the eighth) are *unipolar*, and the condition is brought about in the fœtus by the approximation and fusion of the proximal parts of the two processes above-mentioned. The single process of these unipolar cells after a short course, from the cell-body, divides in a T-shaped manner (fig. 42) into

two processes. Of these one runs towards the periphery and, as it conducts impulses towards the cell, functions as a dendrite; the other enters the central nervous system and, as it conducts impulses away from the cell, functions as an axon. *Structurally, however, the functional dendrite of a unipolar cell is indistinguishable from the axon.*

The body of the nerve-cell is known as the *cyton*. In fixed and stained preparations it consists of a finely fibrillated protoplasmic material in which there are

FIG. 45.—A motor nerve-cell from the anterior horn of the spinal medulla of an ox, stained with methylene blue $\times 500$. The spindle-shaped Nissl's granules are shown. The dendrites and axon are broken off close to the cell.



occasionally patches of a deeper tint, caused by the aggregation of pigment-granules at the sides of the nucleus, as in the substantia nigra and locus cæruleus of the brain. The protoplasm also contains peculiar angular masses of granules which stain deeply with basic dyes such as methylene blue; these are known as *Nissl's granules* (fig. 45). These bodies extend into the dendritic processes but not into the axon, and they disappear (*chromatolysis*) during fatigue or after section of the nerve-fibre connected with the cell. The nucleus is, as a rule, a large, well-defined body, with a relatively small amount of chromatin, and contains a well-marked nucleolus. The small clear area at the point of exit of the axon is termed the *cone of origin*.

In addition to the protoplasmic network described above, each nerve-cell may be shown to have delicate neurofibrils running through its substance (fig. 46); these fibrils are continuous with the fibrils of the axon, and are believed to convey nerve-impulses. A *perinuclear network* of fine branching fibres is a characteristic feature of many nerve-cells.

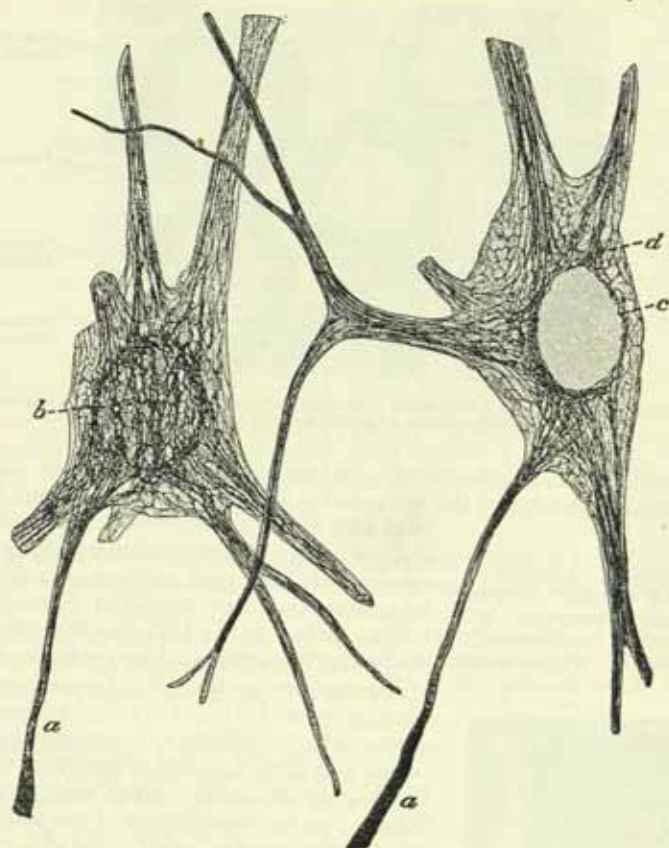
When living nerve-cells are examined by the dark ground illumination method, neither Nissl's bodies nor fibrils of any kind can be seen. The constancy of the occurrence of both these structures in fixed preparations, however, indicates that they represent something specific in the living cell. Histochemical and other studies suggest that Nissl's granules consist of nucleoprotein in combination with iron.

Nerve-fibres are found universally in the peripheral nerves, and in the white matter of the brain and spinal medulla. They are of two kinds—viz. *medullated* or *white fibres*, and *non-medullated* or *grey fibres*.

The *medullated fibres* form the white matter of the brain and spinal medulla, and also the greater part of every cranial and spinal nerve, and give to these structures their opaque, white colour. When perfectly fresh they appear to be homogeneous; but soon after removal from the body each fibre, when examined by transmitted light, presents a double outline or contour, as if consisting of two parts (fig. 47). The central portion is the *axon*; it is surrounded by a sheath of fatty material, staining black with osmic acid, named the *medullary* or *myelin sheath*, which gives to the fibre its double contour; and the whole is enclosed in a delicate membrane, termed the *neurolemma*, *primitive sheath*, or *nucleated sheath of Schwann* (fig. 47). Outside the

neurolemma each nerve-fibre is provided with a fine connective tissue sheath, termed the *endoneurium*. Medullated nerve-fibres vary in diameter from 2μ to 16μ . The *axon* is the essential part of the nerve-fibre, and is always present; the

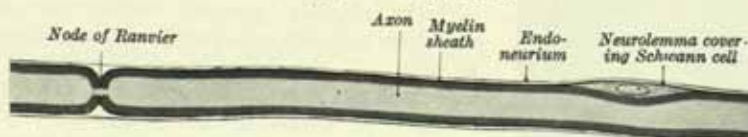
FIG. 46.—Nerve-cells of a kitten, showing neurofibrils. (Ramón y Cajal.)



a. Axon. b. Cyton. c. Nucleus. d. Neurofibrils.

medullary sheath and the neurolemma are occasionally absent, especially at the origin and termination of the nerve-fibre. The axon undergoes no interruption from its origin in the nerve-centre to its termination, and must be regarded as a direct prolongation of a nerve-cell. Nerve-fibres in the white matter of the brain

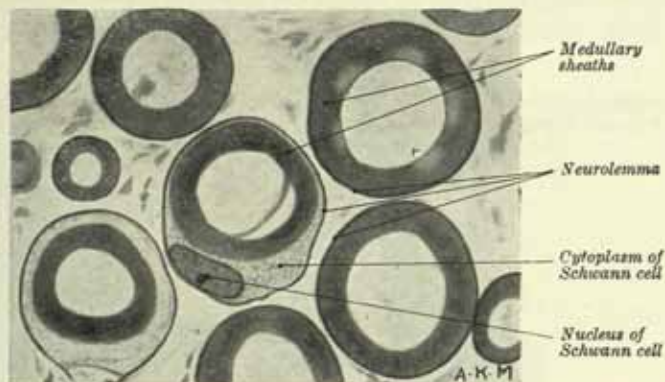
FIG. 47.—Diagram of a medullated nerve-fibre. (W. Holmes and J. Z. Young, *J. Anat.*, 77, 1942.)



and spinal medulla give off twigs known as *collaterals*. These arise from the main fibre at right angles to its course and run into the grey matter, where they terminate usually by arborisation. The axon constitutes about one-half or one-third of the nerve-fibre, being greater in proportion in the fibres of the central nervous system than in those of the peripheral nerves. It is made up of a transparent semifluid substance called the *axoplasm*. After fixation and staining with gold chloride it contains exceedingly fine longitudinally orientated fibrils termed *neurofibrils* and at its termination may be seen to break up into these fibrils.

The *medullary sheath* (figs. 47, 48) is regarded as being a fatty material, termed *myelin*, in a fluid state, which insulates and protects, or possibly supplies nutriment

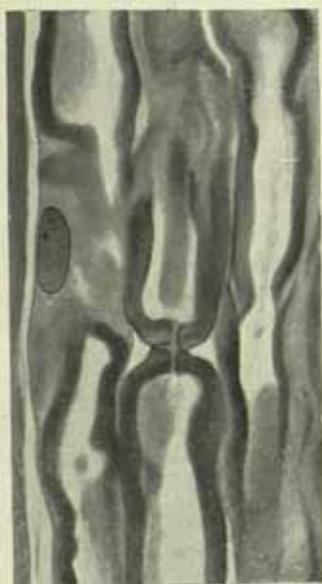
FIG. 48.—Transverse sections through medullated nerve-fibres. (Flemming's solution.) (W. Holmes and J. Z. Young, *J. Anat., Lond.*, 77, 1942.) ($\times c. 1300$.)



The fibre in the centre of the field shows a Schwann cell, with its nucleus and cytoplasm, lying between the myelin sheath, internally, and the neurolemma, externally.

to, the essential part of the nerve—the axon. As a general rule its thickness is proportional to the size of the axon, and is such that it forms about half of the total area of the cross-section of the fibre. With

FIG. 49.—Normal nerve-fibres in longitudinal section. (Drawn from a photomicrograph. W. Holmes and J. Z. Young, *J. Anat., Lond.*, 77, 1942.) ($\times c. 840$.)



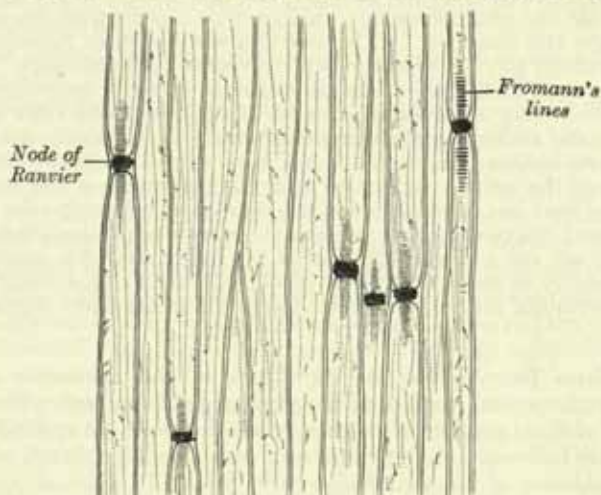
A nucleus of Schwann with its surrounding cytoplasm is seen in the left of the field lying between the neurolemma externally and the myelin sheath internally. The nerve-fibre to which it belongs has been cut obliquely. A node of Ranvier is conspicuous in the centre of the field and in the fibre in the right of the field incisures can be seen cutting obliquely through the myelin sheath. Compare with figs. 48 and 51.

electron microscopy the medullary sheath appears to consist of alternate light and dark concentric laminae. Its continuity is interrupted at intervals of about 1 mm., giving to the fibre the appearance of constriction at these points; these are known as the *nodes of Ranvier* (figs. 47 and 49). The portion of nerve-fibre between two nodes is called an *internodal segment*. The neurolemma is not interrupted at the nodes, but dips in to the constriction without any break in its continuity. Some observers, however, believe that the neurolemma of one internodal segment is connected with that of the adjacent segment at the node by cement-substance. If the fibre be treated with silver nitrate the reagent penetrates the neurolemma at the nodes, and, on exposure to light, reduction takes place, giving rise to the appearance of black crosses (*Ranvier's crosses*) on the axon. Transverse lines, termed *Frommann's lines* (fig. 50), also may be seen beyond the nodes; their significance is not understood. In addition to these interruptions, oblique clefts or *incisures* may be seen in the medullary sheath, subdividing it into irregular portions, which are termed *medullary segments*, or *segments of Lantermann* (figs. 49 and 51); the incisures can be seen best when examined under polarized light (fig. 51). A large number of incisures are displayed by each internodal segment of any peripheral nerve, but they have never been observed in the nerve-fibres of the brain and spinal medulla. It has been suggested* that they provide a mechanism whereby the nerve-fibres can be subjected to minor degrees of stretching and bending without injury, and the fact that the collagenous fibres of the perineurium are arranged in intersecting spirals can be adduced

* P. Glees, *J. Anat., Lond.*, 77, 1943.

as additional evidence in support of this. Opposite the incisures circular collagenous fibres are present in the endoneurium (fig. 51). Medullated nerve-fibres, when

FIG. 50.—Medullated nerve-fibres stained with silver nitrate.

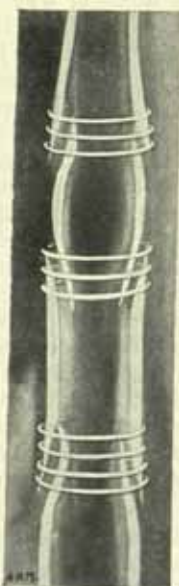


examined in the fresh condition, frequently present a beaded or varicose appearance, due to manipulation and pressure, which cause the oily matter to collect into drops; in consequence of the extreme delicacy of the neurolemma even slight pressure will cause the transudation of the fatty matter, which collects as drops of oil outside the sheath.

The *neurolemma* is a delicate, structureless membrane; here and there beneath it, and situated in depressions in the myelin, are the nuclei of Schwann (fig. 47), each surrounded by a small amount of protoplasm. The nuclei are oval and somewhat flattened, and one is generally found in the middle of each internode. It is uncertain whether the cytoplasm of the Schwann cell is continuous with the neurolemma. *The neurolemma is absent from the medullated fibres of the brain and spinal medulla but nodes of Ranvier are present.*

Degeneration and Regeneration.—When nerve-fibres are cut across, their central ends degenerate as far as the first node of Ranvier, while their peripheral ends degenerate simultaneously throughout their entire length. These changes constitute the process which is known as *Wallerian degeneration*. The medullary sheath of each fibre becomes broken down into droplets of fatty substance, the axon undergoes fragmentation and the fibre becomes converted into a tube, the walls of which are formed by the neurolemma with the endoneurium outside it. Within the tube the cells of Schwann enlarge and increase in number, while macrophages, which are numerous between the 8th and the 25th days after section of the nerve, remove the remains of the axon and the myelin. The cells of Schwann become elongated and appear as overlapping, longitudinally orientated bands of protoplasm (Bungner's bands) along the line of the nerve. As the tubes undergo a certain degree of contraction,

FIG. 51.—Normal medullated nerve-fibre, seen under polarized light. Semi-diagrammatic. (P. Glees, *J. Anat.*, 77, 1943.)



Note the incisures which cut into the medullary sheath and the circular collagenous fibres of the endoneurium which surround them.

the enlarged cells of Schwann may almost fill the available space and they protrude from the peripheral cut ends of the fibres within two weeks of the nerve section.

If the cut ends of the nerve are sutured, regeneration of the fibres takes place by the downgrowth of axon processes from the central cut end. The new fibres grow along the surface of the cells of Schwann and gain the interior of the neurolemmal tube. Several (as many as 20 have been counted) may grow down into the same tube,* although as a rule one, sometimes two, enlarge more rapidly than the others, which gradually atrophy and disappear. It is uncertain whether these numerous fibres are derived from a single axon or whether each represents a separate axon. If the latter proves to be the case, then many of the neurolemmal tubes in the peripheral cut end must fail to receive any incoming axons and this failure would offer an additional explanation for the rather disappointing functional results which often follow the operation of nerve suture.

The ability of the central cut end to send out new fibres is not reduced if it is severed a second time and then sutured at any time up to a year after the initial lesion. On the other hand, the power of the peripheral cut ends to protrude Schwann cells is greatest if they are cut a second time some 2-3 weeks after the initial lesion, and thereafter the ability to do so slowly but steadily declines. As a result fewer fibres succeed in penetrating into a peripheral stump which has been degenerated for a long period.*

Non-medullated fibres.—Most of the fibres of the autonomic system, and some of the cerebrospinal, consist of the grey or gelatinous nerve-fibres—*fibres of Remak*. Each of these consists of an axon to which nuclei are applied at intervals. These nuclei are believed to be in connexion with a delicate sheath corresponding with the neurolemma of the medullated nerve-fibre. In external appearance the non-medullated nerve-fibres are semitransparent and grey or yellowish-grey. The individual fibres vary in size, generally averaging about half the size of the medullated fibres.

THE BODY FLUIDS

Many fluids of widely different character and composition are present in the living body. Of these the majority are localised in their distribution to a single system, e.g. the gastric juice is found only in a part of the digestive system, the cerebrospinal fluid is restricted to the central nervous system, etc. These will be discussed, so far as is appropriate in a student's textbook of human anatomy, under the individual systems, but some of the body fluids have a wide distribution in nearly every part and system of the body, and will be dealt with in this section. They include the blood, the lymph and the tissue fluids, but, although strictly speaking it can scarcely be regarded as a body fluid, the bone marrow also will be included owing to the intimate relationship which it bears to the blood.

Blood† is the most widely distributed of all the body fluids. It is enclosed within, and circulates through, a closed system formed by the heart, the arteries, the capillaries and the veins. All the organs and tissues of the body, with the exception of the refracting media of the eye, sheets of epithelium and cartilage, are permeated by capillaries and as the blood circulates through them it supplies the cellular elements of the tissues with nourishment, and especially with oxygen, and helps to remove the waste-products of their metabolic activities, especially carbon dioxide. Blood is an opaque, rather viscid fluid, of a bright red or scarlet colour when it flows from the arteries, of a dark red or purple colour when it flows from the veins. It is salt to the taste, and alkaline in reaction, the pH of arterial blood ranging from 7.39 to 7.44. Its specific gravity is 1.050 to 1.060 and its temperature is generally about 37° C., though varying slightly in different parts of the body.

If a thin film of blood be examined under the microscope it is seen to consist of a faintly yellow fluid—the *plasma*—in which are suspended numerous minute particles—the *blood-corpuscles*.

The **plasma** is a coagulable fluid, which contains a variety of substances in solution, both crystalloid and colloid. When blood is drawn off into a vessel it will

* W. Holmes and J. Z. Young, *J. Anat.*, Lond., 77, 1942.

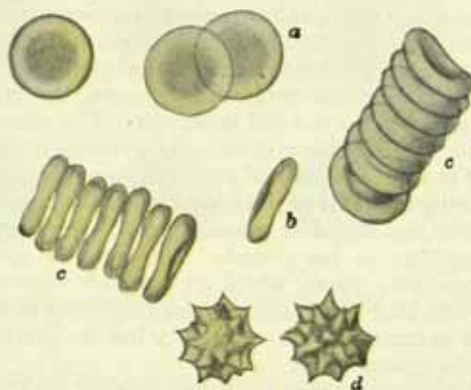
† For detailed account see L. E. Whitby and C. J. C. Britton, *Disorders of the Blood*, 7th edition, London, 1953.

clot within a few minutes, through the transformation of the soluble fibrinogen in the plasma to insoluble fibrin. The latter enmeshes most of the red and white corpuscles and later contracts to express a clear fluid termed *serum*. This differs from the plasma chiefly in that it contains no fibrinogen. Several factors participate in the process of clotting, one of which is Ca^{++} . If citrate or oxalate is added to plasma or whole blood, the calcium is bound in an undissociated form or precipitated, and coagulation does not occur.

The **blood corpuscles** are of three kinds: (1) coloured corpuscles or erythrocytes, (2) colourless corpuscles or leucocytes, (3) blood-platelets.

1. The **coloured or red corpuscles** (*erythrocytes*) are circular discs, biconcave in profile. The disc has no nucleus, but, in consequence of its biconcave shape, it presents, when viewed on the flat by direct illumination, a central area which, when the more prominent peripheral zone of the corpuscle is in focus, appears dark, and so simulates a nucleus (fig. 52a). In stained preparations the central area appears lighter than the periphery. In dried and fixed films the average diameter of the red blood corpuscle is 7.2μ with a range of about 6.7 to 7.7μ and the thickness is from 1.7μ to 2.5μ . The blood owes its red hue to the red blood corpuscles. When seen in large numbers in reflected light the corpuscles appear red but when examined singly in transmitted light their colour appears to be only a faint reddish yellow.

FIG. 52.—Human red blood-corpuscles. $\times 1500$.
Unstained.



a. Surface view. b. Profile view. c. Forming rouleaux.
d. Rendered crenate by hypertonic salt solution.

The average number of red blood corpuscles in a cubic millimetre of blood is about 5,500,000 in a man and 4,800,000 in a woman. The red blood corpuscles of an adult present an aggregate surface of over 3,000 square yards.

The colouring matter of the red blood corpuscles, which is termed *haemoglobin*, is capable of combining with oxygen to form a compound termed oxyhaemoglobin, and it is by virtue of this property of haemoglobin that the red blood corpuscles are able to function as the oxygen-carrying agents in the body. As they circulate through the capillaries in the walls of the air-alveoli of the lungs, the red blood corpuscles take up oxygen and, as they pass through the capillary circulation elsewhere in the body, the lower oxygen tension in the tissues determines the passage of oxygen into them from the blood.

If the mesentery of a living animal be spread out and examined under the microscope, the blood is seen to flow in a continuous stream through the vessels, and the corpuscles show no tendency to adhere to each other or to the walls of the vessels. But when blood is drawn and examined on a slide, the corpuscles often, but not invariably, collect into heaps like rouleaux of coins (fig. 52, c). During life the red corpuscles may be seen to change their shape under pressure so as to adapt themselves, to some extent, to the size of the vessel. They are, however, highly elastic, and speedily regain their form when the pressure is removed. They are readily influenced by the medium in which they are placed. In 0.9 per cent. sodium chloride solution, which is isotonic with human blood-plasma, they are

unaltered in shape. In hypotonic solutions they swell up, become globular, and finally rupture, owing to the passage of water from the surrounding medium into the corpuscle (*endosmosis*). In hypertonic solutions, e.g. 2 per cent. sodium chloride, water passes in the reverse direction (*exosmosis*) and the corpuscle shrinks and becomes crenated in appearance (fig. 52, *d*). The red blood corpuscle is believed by most authorities to be bounded by a membrane enclosing the pigment haemoglobin, water, potassium and other substances in a sponge-like stroma. The membrane, under physiological conditions, shows a selective permeability; for example it is impermeable to haemoglobin, K^+ , and the serum proteins but is freely permeable to water, H^+ , Cl^- , HCO_3^- and glucose. According to another view, the erythrocyte consists of a stroma or sponge-work permeated by the haemoglobin. The stroma and envelope consist of protein together with lipid and other substances.

When stained supravitaly with brilliant cresyl blue recently formed red blood corpuscles can be recognised by their reticular structure and are termed *reticulocytes*. Their number in the blood is increased after haemorrhage or haemolysis and during recovery from nutritional anaemias provided the haemopoietic tissues are functioning normally.

In the adult the red blood corpuscles are all derived from the normoblasts of the red bone marrow (p. 52).

2. The **colourless corpuscles**, or *leucocytes*, are of various sizes. In human blood the majority are rather larger than the red corpuscles, and measure 10μ or more in diameter. On the average from 4,000 to 11,000 leucocytes are found in each cubic millimetre of blood.

They are nucleated cells and exhibit several varieties which are differentiated from each other by their size, nuclear morphology and the staining reactions of the cytoplasm and its contained granules, when present (fig. 53). It is customary to classify the white corpuscles into three main groups, the *granulocytes* or *polymorphonuclear leucocytes*, *lymphocytes* and *monocytes*. The granulocytes are characterised by the presence of well marked chromophil granules in their cytoplasm, both in the living cell and in fixed and stained preparations. They are further classified according to the staining reactions of the granules and the nuclear morphology into *neutrophilic*, *eosinophilic* and *basophilic* granulocytes. Lymphocytes and monocytes are often classed together as *non-granular leucocytes* or *agranulocytes*. When stained by the Romanowsky stains, which are complex mixtures obtained by the interaction of methylene blue and eosin, they are frequently seen to possess numerous fine azurophilic granules in the cytoplasm but in general they are readily distinguished from the granulocytes.

The **neutrophilic granulocytes** or neutrophils are the most numerous of the white corpuscles, their number, in the normal, ranging from 1,500 to 7,500 per cubic millimetre and constituting generally from 33 to 75% of the total leucocytes. They are both amoeboid and phagocytic. In fixed preparations they vary in diameter from 10 to 12μ and contain nuclei which consist of 1 to 5 lobes, often arranged in an S or horseshoe manner and connected together by fine threads of chromatin. The number of lobes in the nucleus is believed to give some indication of the age of the cell, though some of the irregularity may be attributable to the remarkable alterations in shape and form which these cells are capable of undergoing in the living condition. The protoplasm contains many very fine granules which stain with neutral dyes and are therefore called neutrophil granules. They stain a purple tint with the Romanowsky stains.

The **eosinophilic granulocytes** are a little larger than the previous kind and measure, on an average, 11 to 13μ in diameter. They are much less numerous than the neutrophils and their absolute number in normal blood varies from 0 to 400 per cubic millimetre (generally 0% to 6% of the total leucocytes). The nucleus is usually bilobed and the cytoplasm contains an abundance of coarse, strongly eosinophilic granules.

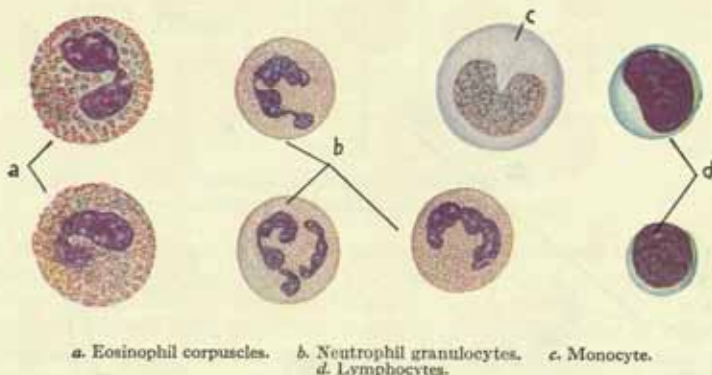
The **basophilic granulocytes** are the least numerous, varying from 0 to 200 per cubic millimetre and comprising from 0% to 2% of the total leucocytes. They are from 8 to 10μ in diameter and the nucleus is kidney-shaped or bilobed and often obscured by the large coarse granules which occur in the cytoplasm and stain intensely with basic dyes. Both these cells and the eosinophilic granulocytes are amoeboid.

Lymphocytes are derived from lymph glands and lymphoid tissues and can be

observed in lymph from the thoracic duct. Their number in the circulating blood varies from 1,000 to 4,500 per cubic millimetre where they comprise from 15% to 60% of the total leucocytes. The nucleus, which is large and spherical or slightly indented, is surrounded by a narrow rim of pale basiphilic cytoplasm. The cells are actively amoeboid in the body but are immobile in supravitral preparations. They are not phagocytic. Lymphocytes are usually designated *large* or *small* according to their size and morphology. The small lymphocyte is about the size of a red blood cell with a deeply staining nucleus and a narrow rim of clear cytoplasm whilst the large lymphocyte, which is believed to be the younger form, measures 12μ to 15μ in diameter, has a pale, large, round or slightly indented nucleus with more abundant cytoplasm around it. Intermediate types occur. It has been shown that the lymphocytes fix the vaccinia virus used in Jennerian vaccination and serve as its carriers throughout the body. It is not unlikely that other viruses may spread in the same way.*

Monocytes are generally the largest of the leucocytes and measure on an average 10μ to 22μ in diameter. The numbers in the blood range from 0 to 800 per cubic millimetre and comprise from 0 to 9% of the total leucocytes. The nucleus is

FIG. 53.—Varieties of leucocytes found in human blood, stained with Leishman's stain. $\times 1500$.



a. Eosinophil corpuscles. b. Neutrophil granulocytes. c. Monocyte. d. Lymphocytes.

typically eccentric and horseshoe-shaped but may be round or oval when it may be difficult to distinguish the cell from a large lymphocyte. The cytoplasm is abundant and stains a pale greyish blue with the Romanowsky stain. Numerous very fine dust-like reddish-blue granules may be present in the cytoplasm giving it a ground glass appearance. The cells are actively amoeboid and phagocytic. When stained supravitally with neutral red, monocytes are characterised by the presence of numerous red vacuoles in the cytoplasm, frequently arranged as a 'rosette' in the concavity of the nucleus.

The neutrophil, eosinophil and basiphil corpuscles have their precursors in the myelocytes of the bone-marrow; they are derived, respectively, from the neutrophil, eosinophil and basiphil myelocytes. The lymphocytes come from the lymphoblasts formed in the germinal centres of lymphoid tissue. The origin of the monocytes is uncertain. They are regarded by most authorities as being derived from the reticulo-endothelial system (p. 53) and by others as modified lymphocytes. According to Maximow † monocytes are derived from lymphocytes and are capable of transformation into histiocytes (p. 12) but this view is not generally accepted.

3. The **blood-platelets** (fig. 54) are oval, colourless, refractile discs, varying in size from 2 to 3μ and numbering between 250,000 and 500,000 per cubic millimetre. They are possessed of no demonstrable nucleus or chromatin material, but consist of a homogeneous cytoplasm in which are embedded a number of highly refractile granules. These granules are usually grouped centrally, and in fixed preparations they may be so closely packed as to present the appearance of a more or less homogeneous mass, closely simulating a nucleus.

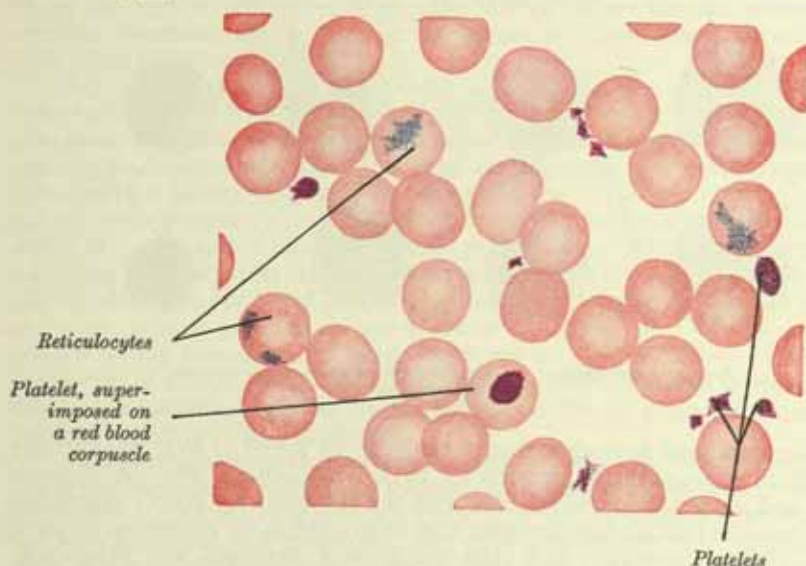
* J. M. Yoffee and E. R. Sullivan, *J. Exp. Med.*, **68**, 1946.

† A. Maximow and W. Bloom, *Text-book of Histology*, London, 1937.

In rapidly prepared blood smears they appear as oval, round or irregular corpuscles which stain a pale blue or mauve with dark purple granules with the Romanowsky stains. In the circulating blood they are discrete; when the blood is shed they show a marked stickiness and tend to adhere to any wettable surface with which they come in contact. Under these circumstances they aggregate in clumps and disintegrate, which makes the study of their morphology and enumeration difficult. They are best studied by collecting the blood at once into an isotonic anticoagulant fixative which prevents clumping and disintegration of the platelets. They can be stained by the addition of brilliant cresyl blue to the fluid. The blood should be collected directly into a drop of the fluid placed on the skin or into a syringe or pipette already containing some of the diluting fluid. Platelet counts may be made directly in a counting chamber or indirectly by determining their ratio to the red blood corpuscles in the sample.

Platelets arise from the megakaryocytes or giant cells in the haematopoietic tissue. The functions of the blood platelets are not fully understood but they are known to play an important role in the process of coagulation. When blood is shed and comes into contact with a wettable surface they disintegrate and liberate

FIG. 54.—Blood-platelets. Highly magnified. From a preparation made by Dr. R. L. Waterfield, and stained with a modification of Leishman's stain.



factors which are concerned with others in the formation of active thromboplastin. This, in the presence of calcium ions, interacts with the inactive prothrombin of the plasma to form the enzyme-like substance, thrombin, which converts fibrinogen into fibrin. In addition platelets are necessary for the retraction which the blood clot normally undergoes and it would seem that these elements are essential to the formation of a firm thrombus. Masses of contact platelets can be found adhering to the fibrin network formed during coagulation particularly at the intersections of the fibrin threads. By their agglutination in the body, platelets may form small masses within the blood vessels, called white thrombi, which may adhere to the wall or plug the vessel. They are also believed to be a vehicle for the substance, serotonin, which is capable of producing constriction and modifying the permeability of the capillaries.

Blood-groups.—The use of blood transfusion as a therapeutic measure, i.e. the withdrawal of blood from one individual and its intravenous injection into another, has brought to light the fact that human beings fall into four different blood-groups, known as O, A, B, and AB. Groups A and B are incompatible with each other and, when a member of one group is transfused with blood from a member of the other, his red blood corpuscles become agglutinated, often with a fatal result. The agglutination is brought about by the interaction of two substances in the blood

agglutinin, which is carried by the red blood corpuscles, and *agglutinin*, which is carried by the plasma. The blood of group A contains agglutinin A and agglutinin β (or anti-B); group B, agglutinin B and agglutinin α (or anti-A); group AB, agglutinogens A and B, but no agglutinins; and group O, no agglutinogens but both α and β agglutinins.

Members of group O are often referred to as *universal donors* since, as a rule, no agglutination occurs when their blood is transfused into members of any of the groups. Similarly members of the group AB are often designated *universal recipients* for, as a rule, they can be transfused with blood from any of the groups without harmful effects. These terms however are unsatisfactory, and even dangerous, as in both circumstances dangerous and even fatal reactions can occur when the recipient's blood contains an unusually high titre of agglutinins. In all cases where it is possible it is best to employ blood of the group to which the recipient belongs. The interrelationships of the blood groups may be expressed in tabular form:

		Recipients			
		O	A	B	AB
Donors	O	o	o	o	o
	A	+	o	+	o
	B	+	+	o	o
	AB	+	+	+	o

o indicates satisfactory transfusions.

+ indicates agglutination of in-going cells.

The blood-groups occur in different proportions in different races. In England the O group is the largest (45.8 per cent.); followed by the A group (42.2 per cent.); the B group (8.7 per cent.); and the AB group (3.2 per cent.). Each group has its own particular genetic basis and conforms to the Mendelian laws of heredity.

Further work has resulted in the discovery of another antigen, which is present in 85 per cent. of individuals, irrespective of their particular blood-groups. It has been termed the Rh antigen, as it is found to be present normally in the blood of Rhesus monkeys. No corresponding naturally occurring antibody has been identified, but, if an Rh negative individual is transfused with blood from an Rh positive donor, he may develop an anti-Rh antibody in his blood. If he then receives a second transfusion from an Rh positive donor he is liable to suffer a haemolytic reaction. It has been shown that if an Rh negative woman becomes pregnant and the foetus is Rh positive, anti-Rh factors develop in the maternal blood and, under those circumstances, if the mother subsequently receives a transfusion from a Rh positive donor, a haemolytic reaction may occur, which, if severe, may prove fatal. If she becomes pregnant again and the second or subsequent child is Rh positive then the anti-Rh antibody level in the mother's blood may be raised still further. In a proportion of cases the antibody is transmitted across the placenta into the foetal circulation. In this circumstance, the newborn child may develop an acute haemolytic anaemia, the condition known as *erythroblastosis foetalis*. The first born Rhesus positive child escapes this disease unless the mother has had a previous abortion or been transfused with blood containing the Rh antigen, presumably because the antibody level at the time is not high enough to produce haemolytic symptoms.

The presence of the Rh agglutinin on the red cells is determined by a pair of genes Rh and rh, of which Rh is dominant, giving three possible combinations of genes (genotypes), Rh Rh, Rh rh, and rh rh in the offspring. As Rh is dominant over rh, Rh agglutinin will be present on the red cell if the genotype is Rh Rh or Rh rh. When the father is Rh positive (genotype Rh Rh or Rh rh) and the mother is Rh negative (genotype rh rh), all the children will be Rh positive if the genotype of the father is Rh Rh, but, if the genotype of the father is Rh rh, there is an equal chance of any child being positive or negative.

Other agglutinogens have been identified in human blood, such as M and N,

but, as no corresponding agglutinins are present naturally in blood plasma these two have no importance in connexion with transfusion. Their existence, however, can prove of real value in medico-legal cases, as their detection may lead to the identification of the source of origin of blood-stains or blood samples.

The **lymph** is a colourless or slightly yellow, watery fluid, of sp. gr. about 1.015. It is contained in lymph vessels, which commence as lymph capillaries in nearly all parts of the body. Its composition varies with the functional activity of the tissue and the region from which it flows. Its constituents are similar to those of plasma but the protein content is generally much lower and the relative proportions of the protein fractions are different. During digestion much of the absorbed fat from the intestine enters the lymph, which may become milky in appearance and is known as *chyle*. In microscopic examination using dark field illumination the fat is visible as minute globules about 1μ in diameter known as *chylomicrons*. These may be seen also in the blood after a fatty meal. The composition of lymph is similar to that of tissue fluid and the lymphatic system should be regarded as one of the routes for the drainage of this fluid and particularly for the return to the blood of the proteins here which do not readily re-enter the capillaries. Its circulation from the smaller to the larger lymph vessels is determined to a large extent by the pressure exerted by the muscles during active movements and it therefore tends to be slow and intermittent, but the presence of numerous valves ensures its flow in one direction only. Finally the lymph is poured into the veins through the medium of the thoracic duct (p. 882) and the right lymphatic duct.

The chief cellular elements in lymph are lymphocytes. These cells are identical with the small lymphocytes of the blood; they are much more numerous in lymph after it has passed through a collection of lymphoid tissue, such as a lymph node (p. 879). The presence of an occasional red blood corpuscle does not imply any abnormality.

The lymph vessels and the lymph nodes are described in detail on pp. 878 to 881.

The **tissue fluid** is a colourless, watery fluid which occupies the tissue spaces in areolar and fibro-areolar tissues and the cœlomic spaces of the pericardial, pleural and peritoneal sacs. It is believed that its composition is approximately identical with that of lymph obtained from the same part of the body. Under normal conditions tissue fluid is small in amount and difficult to collect for examination. Under abnormal conditions, such as chronic venous congestion, fluid accumulates in the tissue spaces producing œdema, and can readily be drawn off and examined. This fluid contains a relatively low protein concentration as compared with lymph, but it must be remembered that under such circumstances water is no longer reabsorbed by the blood capillaries in the normal way and the tissue pressure rises to a level at which filtration of protein from the capillaries ceases.

The **bone marrow** is a soft pulpy tissue which is found not only in the cylindrical marrow cavities of the long bones but also in the spaces of the spongy substance of all bones and even in the larger Haversian canals. It differs in composition in different bones and at different ages, and occurs in two forms, *yellow marrow* (*medulla ossium flava*) and *red marrow* (*medulla ossium rubra*).

At birth there is red marrow throughout the skeleton. After about 5 years of age the red marrow is gradually replaced in the long bones by yellow marrow. The replacement commences earlier and is more advanced in the more distal bones. Further, in each successive bone the replacement, in general, proceeds from the distal to the proximal end though some maintain that it commences in the centre of the shaft and extends in both directions but more rapidly in the distal. By 20 to 25 years of age the red marrow persists only in the vertebrae, sternum, ribs, clavicles, scapulae, hip bones, skull bones and in the upper ends of the femora and humeri. In old age the marrow of the skull bones undergoes degeneration and is then termed *gelatinous marrow*.

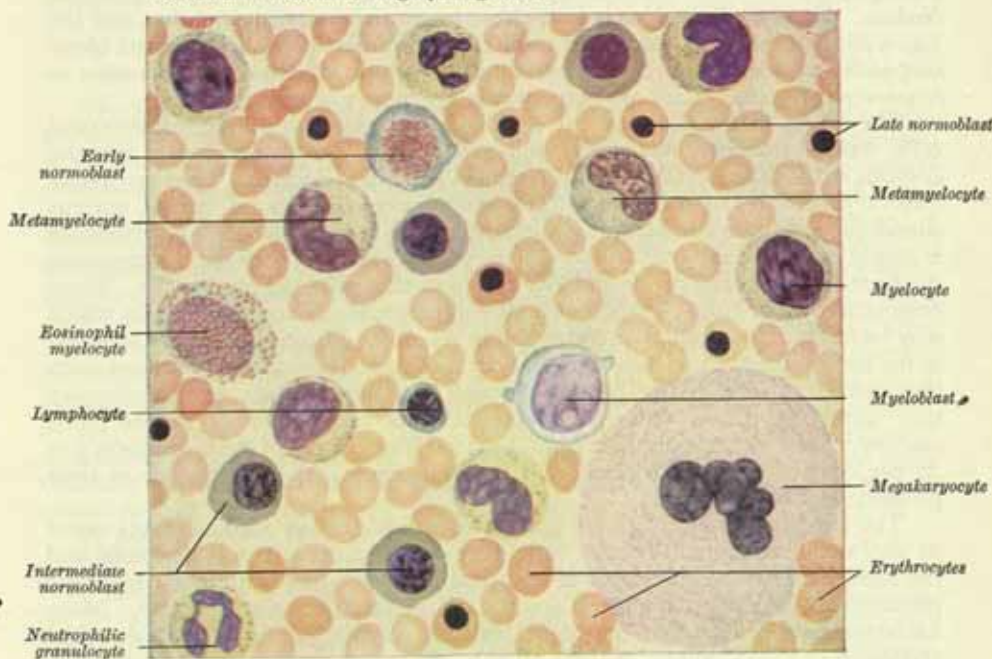
The *yellow marrow* consists of a basis of connective tissue, supporting numerous blood-vessels and cells, most of which are fat-cells although some are marrow-cells such as predominate in red marrow.

The *red marrow* consists of a framework of reticular connective tissue with argyrophilic fibres and attached phagocytic cells, containing in its meshes a variety of blood cells and their precursors and a few fat cells. Small nodules of lymphoid tissue are also scattered through it. No lymph vessels have been demonstrated however in yellow or red marrow. The vascular supply of the bone marrow is

derived from the nutrient artery to the bone and drained by the accompanying vein. The artery divides into fine branches which ramify in the marrow and end in a rich endothelially lined plexus of thin walled sinusoids. A large number of these blood sinuses are collapsed at one time and are frequently referred to as intersinusoidal capillaries. Sabin * and her co-workers believed that the formation of red blood cells occurred intravascularly within these intersinusoidal capillaries and the cells normally entered the circulation only when mature, whereas the leucocytes formed extravascularly. In the early embryo, however, the red blood cells are formed in the mesenchyme and some authorities now believe that all the cells of the blood are formed extravascularly. Nerves occur in the bone marrow only in association with the larger blood vessels.

In embryonic life the first blood cells, the primitive erythrocytes, develop in the mesenchyme of the yolk sac and chorion. Haematopoietic foci appear later in

FIG. 55.—A smear preparation of normal human bone marrow, obtained by sternal puncture. Composite figure, drawn from a number of normal smears prepared by Dr. R. L. Waterfield and stained with a modification of Leishman's stain. Highly magnified.



the intraembryonic mesoderm particularly in the liver and spleen. After the end of the third month of intra-uterine life the bone marrow becomes the chief site of the formation of red blood cells and granulocytes. The haematopoietic foci in the liver and spleen normally disappear soon after birth.

Before describing the free cells which occupy the meshes of the bone marrow reticulum, it is necessary to consider briefly the divergent views concerning the genesis of the blood cells. According to the monophyletic school, which will be followed in this description, all the blood cells are derived from the common stem cell, the *haemocytoblast* which is present in the bone marrow and lymphoid tissue and is derived from the primitive mesenchymal cell in the reticulum. The polyphyletic school, however, maintains that the several varieties of blood cells arise from different stem cells, whilst the dualistic school recognises only two specific stem cells, one in the bone marrow for the myeloid elements and the other in lymphoid tissue and responsible for the lymphocytes. There is general agreement on the mesenchymal origin of the stem cells but divergent views concerning, in particular, the potentialities and interrelations of the earliest recognisable stem cells. Despite considerable confusion in terminology of the various stages in the development of the blood cells there is good agreement concerning their morphological characteristics.

Haemocytoblasts are large cells, over 15μ in diameter, with large lightly-staining nuclei surrounded by a narrow rim of clear non-granular cytoplasm. They resemble large lymphocytes and are considered by some authorities to be identical with them.

The earliest identifiable specific cell in the erythrocyte series is the *proerythroblast* (pronormoblast). It measures 12 to 15μ in diameter and possesses a large nucleus, in which the chromatin tends to aggregate into clumps, with a well-marked nucleolus. The cytoplasm is small in amount, basiphilic in reaction and devoid of haemoglobin. It divides by mitosis to produce the *early normoblasts* (basiphilic normoblast) in which the clumping of the nuclear chromatin is distinct, but nucleoli are absent and the cytoplasm is devoid of haemoglobin. These cells multiply by mitosis to give rise to *intermediate normoblasts* (polychromatic normoblasts). These are smaller cells which multiply by mitosis and display a progressive condensation of the nuclear chromatin together with an increasing acidophilia due to the appearance of haemoglobin in the cytoplasm. Having acquired their full complement of haemoglobin they mature, without further division into the *late normoblasts* (orthochromatic normoblasts), measuring 7 to 10μ in diameter and distinguished by their characteristic acidophilia and uniformly dense pyknotic nucleus. Finally, the nucleus is lost, either by extrusion or disintegration, and the non-nucleated red blood corpuscle results. The earliest non-nucleated red blood corpuscles are identifiable by the presence of reticular material and are known as *reticulocytes* (p. 46). They are numerous in the bone marrow (fig. 55).

The stages in the development of granulocytes are: primitive mesenchymal cells, haemocytoblasts, *myeloblasts* and *myelocytes*. The myeloblasts arise by division of the haemocytoblasts and resemble large lymphocytes. They are motile cells varying from 11μ to 18μ in diameter and possess a large round, or oval, nucleus containing a delicate chromatin network and two or more nucleoli. The cytoplasm is deeply basiphilic and contains no specific granules staining with the Romanowsky methods. Myeloblasts divide and give rise to smaller cells, the myelocytes. These possess an oval or kidney-shaped nucleus and progressively acquire granules which may be basiphil, neutrophil or eosinophil in reaction. Mitotic figures are common in the more primitive varieties of myelocytes, but when they take on their final form they cease to divide. After passing through a transition stage (*metamyelocytes*), they enter the blood stream. Metamyelocytes are numerous in the bone marrow. Cells indistinguishable from the small lymphocytes of the blood form 5 to 20 per cent of all the nucleated cells in the marrow; the significance of their presence is discussed below.

The *megakaryocytes*, which are giant cells with multilobar nuclei (fig. 55), occur in very small numbers in normal bone marrow. The cytoplasm is basiphilic and the membrane which surrounds it is so fragile that it frequently tears in smear preparations, allowing the nucleus and the cytoplasm to become separated. Many haematologists believe that the blood-platelets are derived from small detached fragments of the cytoplasm of these cells (p. 48).

Red bone marrow is thus a highly cellular tissue consisting of a fine connective tissue reticulum and containing in its meshes a variety of cells representing the developmental stages of both the red and white blood cells series. Samples of red bone marrow obtained by aspiration from a sternal puncture contain, in the normal adult, from 20,000 to 100,000 cells per cubic millimetre, in which the distribution of the various cell types is as follows:

	Percentage
Granulocytes	
Neutrophil	10-40
Eosinophil	0-4
Basiphil	0-1
Metamyelocytes	10-25
Myelocytes	2-8
Lymphocytes	5-20
Monocytes	0-5
Plasma cells	0-1
Late Normoblasts	7-19
Early and Intermediate Normoblasts	4-15
Proerythroblasts	0-4
Haemocytoblasts	0-1

The presence of lymphocytes in red marrow merits further consideration. Although it is generally accepted that these cells are formed in lymphoid tissue and pass, via the efferent lymph vessels and the thoracic or right lymphatic duct, into the bloodstream, there is no general agreement regarding their subsequent history.

The number of lymphocytes circulating in the blood at any one time can be estimated and can be compared with the number entering the bloodstream in a given period from the thoracic duct. Yoffey * has estimated that the lymphocytes in the blood are replaced twice in 24 hours and the fate of this huge number of cells (5,000,000,000 in a dog weighing 10 kgs.) constitutes a very perplexing problem. No convincing explanation has yet been offered. Recently it has been suggested that the small lymphocytes are immature cells which do not undergo development until they reach the red marrow, where they constitute stem cells for the myelocytes and normoblasts. Tissue culture investigations provide additional evidence that the small lymphocytes are immature cells but tend to suggest that their possibilities are limited and that they form the monocytes only.

Consideration of all the evidence leads to the conclusion that the problem presented by the life-history of the lymphocyte has not yet been solved.†

THE MACROPHAGE OR RETICULO-ENDOTHELIAL SYSTEM.‡

The macrophage or reticulo-endothelial system is a collective term for a widespread system of highly phagocytic cells. Its cells are numerous and are characteristically present in large numbers in certain situations in the body. Under appropriate stimulation they are capable of detaching themselves from the tissues, which, when they are resting, they help to form and of acquiring mobility which is amoeboid in character. In ordinary stained histological preparations they display no characteristic morphology by which they can be distinguished with certainty. They can be identified by their marked affinity for inert particles and certain colloidal dyes, when these are injected into the living animal. Inert particles such as Indian ink when injected into the blood stream of the living animal are taken up by the intravascular components of the macrophage system as well as by the granulocytes in the blood. Diffusible colloidal dyes, such as trypan blue, when injected into the vascular system, are taken up by both the intravascular and extravascular components of the reticulo-endothelial system. Endothelial cells, fibroblasts, lymphocytes and many other cells may take up small amounts of the dye but are usually readily distinguished by quantitative differences from the cells of the reticulo-endothelial system.

In the resting condition cells of the reticulo-endothelial system occur in considerable number in the following situations:—(1) Connective tissues, where they have already been described as histiocytes. In neuroglia the microglial cells (p. 38) belong to this system. In the subserous connective tissue of the pleura and peritoneum the macrophages are frequently aggregated and appear as white streaks, known as *taches laiteuses*, close to the small lymphatic trunks. (2) Blood, where they are represented by the mononuclear cells. There is evidence that these have migrated into the blood stream from the tissues and are distinct from other circulating white blood cells. (3) Lining the blood sinuses of the bone marrow, spleen, liver (where they are termed von Kupffer's cells), medulla of the suprarenal gland and the anterior lobe of the hypophysis. (4) In the reticular tissue of the spleen and lymph nodes and (5) in the meninges, where they are known as *meningocytes*.§

Endothelial cells in general and the circulating leucocytes of the blood are not included in the system.

The origin and genesis of certain large cells known as the 'dust cells' which occur in the lungs and are believed to be concerned with the removal of particulate matter and bacteria is uncertain. Whether they arise locally or are carried to the lungs in the blood stream is undecided. It is claimed that the blood in the right side of the heart is richer in large phagocytes than that on the left side and that most of the large phagocytes are removed in the lungs.

* J. M. Yoffey, *J. Anat., Lond.*, 70, 1936.

† C. K. Drinker and J. M. Yoffey, "Lymphatics, Lymph and Lymphoid Tissue," *Harvard University Monographs on Medicine and Public Health*, No. 2, 1942.

‡ H. M. Evans, *Amer. J. Physiol.*, vol. 37, 1915; L. Aschoff, *Lectures on Pathology*, New York, 1924; H. H. Woollard, *Recent Advances in Anatomy*, London, 1927.

§ H. H. Woollard, *J. Anat., Lond.*, 58, 1924.

On account of their amoeboid and phagocytic properties the cells of the macrophage system form one of the most important defences of the body against micro-organisms. Under appropriate stimulation the cells proliferate freely. In addition there is evidence that they are concerned, along with other cells, in the production of antibodies. Repeated injections of particulate matter into an animal can 'block' the normal function of the macrophages, so that subsequent destruction of micro-organisms is hindered. Though the destruction of aged red blood cells is believed to occur in the circulation, it is claimed that the released haemoglobin is normally removed and metabolized by the macrophage system. This results in the production of bilirubin, which is excreted by the liver, and the accumulation in the cytoplasm of the macrophages, until required, of a complex iron-containing pigment called *ferritin*. There is evidence also that the macrophage system is concerned in the metabolism of lipoids; it is extensively involved in certain disorders of lipoid metabolism.

EMBRYOLOGY

INTRODUCTION

THE series of changes which constitutes the development of the human body commences when the female germ-cell, or ovum, is fertilised by a male germ cell, or spermatozoön, and terminates when the adult condition is reached. Embryology deals with the changes which occur prior to the birth of the child.

Two processes, intimately associated with each other although essentially distinct, are responsible for the transformation of the single-celled ovum into the complex form of the newly born child. These processes are (1) *growth* and (2) *differentiation*. Growth, with certain exceptions to be noted later, involves increase in size brought about by cell division and is dependent on the ingestion of a sufficient quantity of the appropriate type of nourishment. The process of growth is not a simple one, for in certain situations it must be accompanied by a process of absorption, which is just as much an indication of growth activity as increase of size. For example, as the mandible increases in size, the anterior part of its ramus is constantly being remodelled by a process of absorption, while the opposite phenomenon of bone deposition is occurring along its posterior border.

Differentiation is the process whereby a group of cells assumes certain special characteristics which enable them to carry out some particular function. It was long believed that all the stimuli which lead groups of cells to undergo differentiation were inherent in the cells themselves and were directly due to an hereditary factor, but this view requires considerable modification in the light of recent experimental work. The earliest cells derived from the fertilised ovum are *totipotent*, i.e. any one of them may go on to form a complete embryo, but this stage is succeeded by a transient phase of *plasticity*, in which cell groups, though no longer totipotent, remain pluripotent and, though destined normally to form a particular type of tissue, may form a totally different tissue if exposed to abnormal influences. The stage of plasticity passes into the stage of *chemo-differentiation*, in which there is a redistribution of certain of the chemical constituents of the cytoplasm and the potencies of the cells become further reduced. Thereafter groups of cells undergo visible differentiation (indicated by changes in their histological characters or by a modification in the arrangement and shape of the group) and this can frequently be shown to be dependent on some alteration in their environment. Under normal conditions a patch of the head ectoderm which overlies the developing optic vesicle undergoes a series of changes and gives rise to the lens. In the frog (*Rana fusca*) transplantation of the optic vesicle into the tissues of the abdominal wall results in failure of the lens to develop in its normal site but the ectoderm under which the transplant lies forms a lens in the ordinary way. This is an example of *dependent differentiation* and many other examples might be cited.

Spemann* has shown that the cells situated in the dorsal lip of the blastopore determine the position of the axial structures, the brain, spinal medulla, notochord, somites, etc., which represent the most fundamental parts of the embryo. They exercise this determining influence by elaborating a chemical substance which acts directly to induce the formation of the notochord and acts indirectly through the notochord to induce the differentiation of the covering ectoderm into neural tissue. This organising power of the cells of the dorsal lip of the blastopore can be exercised on tissues of other embryos, provided that their cells are sufficiently plastic to respond. Spemann,† working on amphibian larvæ, transplanted portions of the dorsal lip of the blastopore into an undifferentiated region of another embryo. As a

* H. Spemann, *Arch. Ent. Mech.*, **43**, 1918.

† H. Spemann and H. Mangold, *Arch. Mikr. Anat. und Ent. Mech.*, **100**, 1924.

result the transplant and the tissues of the host interacted on one another in such a way that a secondary, incomplete embryo, with neural tube, notochord, somites, etc., formed in the tissues of the host. This, and other experiments of a similar nature, demonstrate the latent potencies of undifferentiated cells and the organising power of the cells situated in the dorsal lip of the blastopore.

At a later stage, when functional activity has been established, further differentiation occurs in response to stimuli produced in this way. Thus, after the establishment of the blood-vascular circulation, the walls of the arteries become differentiated and they thicken in response to the rising arterial blood-pressure which is associated with the increasing force of the heart. Such changes may be regarded as examples of *functional differentiation*.

Many tissues of the adult body retain their potencies to a large extent and are capable of taking on new characters when an appropriate stimulus is received, always provided that their cells are still able to reproduce themselves. Such processes frequently occur in the formation of tumours and in other pathological conditions. They serve to demonstrate that the individual cells do not possess any inherent tendency to take on special characters but that their future depends on their potencies and their environment.

Differentiation is the result of the activities of certain *growth organisers*, such as the dorsal lip of the blastopore, but it would appear that the latter are unable to control the growth after a certain stage has been reached. For example, a portion of an optic vesicle, if transplanted, may continue to grow and may give rise to a complete vesicle, independently of the environment in which it may be placed. If it fails to behave in this way, the transplant dies and is absorbed. The regulation and control of the extent of growth processes are apparently effected by the hormones secreted by the ductless glands, but nothing is known of the way in which they exercise their influence.

The importance of embryology.—To the student of medicine the study of human embryology is of real value, for it renders intelligible many of the facts of human anatomy which are otherwise meaningless or anomalous. In its early stages the body of the embryo exhibits an almost perfect symmetry, which, owing to a variety of causes, becomes considerably obscured in certain regions of the body in the adult. The normal processes of development supply not only the reasons for these differences but also the explanations of those departures from the normal which constitute congenital abnormalities or defects.

In addition to its value as an aid to the interpretation of human anatomy, embryology possesses importance on account of the evidence which it provides regarding the phylogeny of man. The changes which any embryo undergoes in the course of its development repeat—often, it is true, in a very abridged form—the changes which occurred in the embryos of its ancestral forms. The embryos of all vertebrates exhibit a stage in which gill-arches and clefts are present in the neck region. In fishes the cleft membranes break down and the gills develop and persist as essential functional structures in the adult form. In all air-breathing vertebrates this stage, although transient, nevertheless occurs, but, in the human embryo, the cleft membranes never break down. In many cases the constituent parts of the arches become modified and adapted for new uses, a remarkable and noteworthy fact to which reference will be made repeatedly in the following pages.

Having regard to the main purpose of this work, it is impossible, in the space available in this section, to describe or illustrate fully all the changes which occur during the development of the human body. Only the principal facts are given, and the student is referred for further details to one or other of the text-books * on embryology.

THE OVUM

The ova develop in the ovary, which is the sexual gland of the female. The primordial sex cells are differentiated at a very early stage of development (p. 211) and by their repeated division give rise to a number of smaller cells, termed

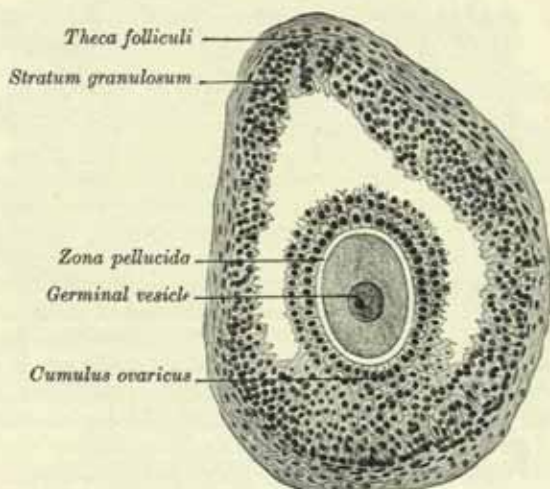
* *Manual of Embryology*, J. E. Frazer, 1931; *Human Embryology*, W. J. Hamilton, J. D. Boyd and H. W. Mossman, 2nd edition, 1952; *Analysis of Development*, B. H. Willier, P. A. Weiss and V. Hamburger, 1955.

oögonia. After a time the *oögonium* ceases to divide and passes through a resting phase. It has now become an *ovum* or *primary oöcyte*, and the changes which it subsequently undergoes constitute the maturation or ripening of the ovum.

Human ova vary from about 117μ to 142μ in diameter, according to their stage of development. They are contained within the vesicular (Graafian) follicles of the ovaries; as a rule each follicle contains one ovum, but sometimes two or more are present. Each ovum is at first invested by a single layer of cubical cells, termed the *follicular layer*; these cells by multiplication form several layers. At a later stage a cavity filled with fluid appears amongst the cells, and gradually splits them into an inner stratum, termed the *cumulus ovaricus*, and an outer, termed the *stratum granulosum*; but at one place the two strata remain in continuity. The stratum granulosum is enveloped by a sheath derived from the stroma of the ovary* (fig. 56) and termed the *theca folliculi*. By the enlargement and subsequent rupture of a follicle at the surface of the ovary, an ovum, surrounded by the cells of the cumulus, is liberated and enters the uterine tube, through which it is conveyed to the cavity of the uterus. Unless the ovum is fertilised it is discharged from the uterus, but if fertilisation takes place it is retained there and is developed into a child, which is born at the end of ten lunar months of twenty-eight days or nine calendar months.

Although the ovum (fig. 57) is very much larger than the ordinary cell, it resembles it closely in structure and general appearance, but distinctive names are given to its several parts; thus, the cell-substance is known as the

FIG. 56.—A section through an ovarian follicle of a cat. $\times 50$.



yolk or *oöplasm*, the nucleus as the *germinal vesicle*, and the nucleolus as the *germinal spot*. The ovum is surrounded by a thin *vitelline membrane* outside which is a thicker, transparent envelope named the *zona pellucida*. When the ovum is liberated from the vesicular follicle, several layers of cells, derived from those of the cumulus ovaricus, adhere to the outer surface of the zona pellucida, and collectively constitute the *corona radiata*.

Usually only one follicle matures fully and ruptures in each menstrual cycle but in the same period several follicles, although developing normally for a time, subsequently show atretic changes and degenerate. They are invaded by blood vessels and connective tissue which ultimately replace them.

The **yolk** comprises (1) *cytoplasm* similar to that of the ordinary animal cell (p. 1) and frequently termed the *formative yolk*; (2) *deutoplasm* or *nutritive yolk*, which consists of fatty droplets containing lecithin—a phospholipin closely allied to and found with the animal fats.† In the mammalian ovum the deutoplasm is extremely

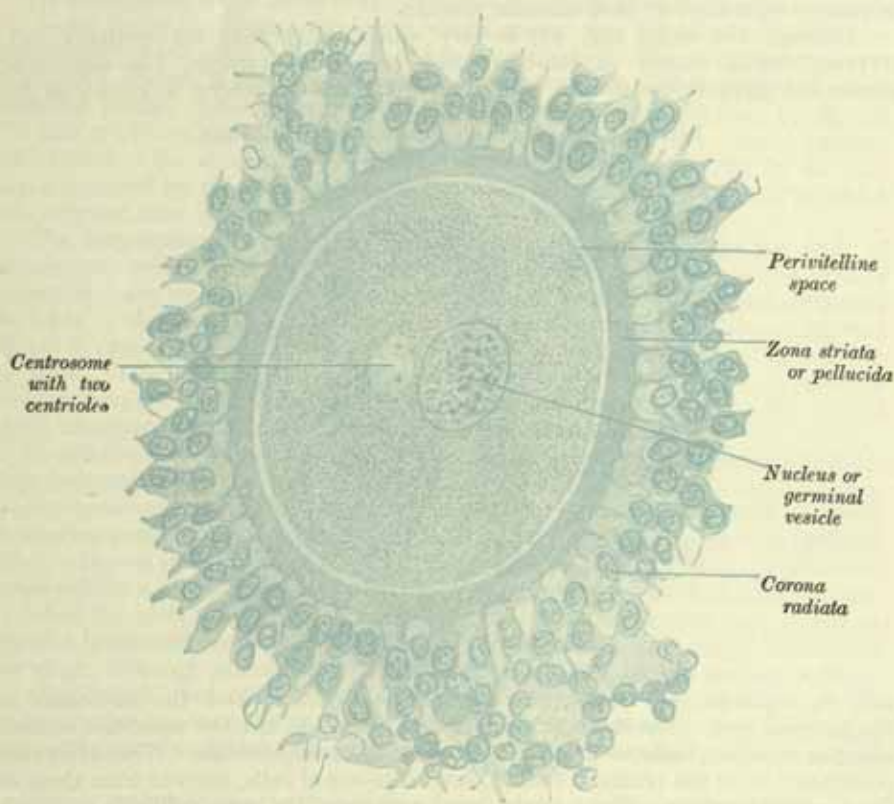
* For further particulars, see description of the ovary under Splanchnology.

† Arthur Robinson (*Proc. Anat. Soc. Great Britain and Ireland*, 1923, p. 109) has shown that unsaturated fat, demonstrable by osmic acid, is practically absent from human ova, and from the ova of rats and mice, but is present in large amount in the ova of dogs and ferrets, where it forms the greater part of the volume of the ova.

small in amount, and nourishes the embryo in the early stages of its development only, whereas in the egg of the bird there is sufficient to supply the chick with nutriment throughout the whole period of incubation. The mode of distribution of the deutoplasm within the egg varies in different animals; it is almost uniformly dispersed throughout the cytoplasm. A *centrosome* and *centrioles* are sometimes present and lie in the immediate neighbourhood of the nucleus; the centrioles of the ovum disappear when the female pronucleus (p. 60) is formed after fertilisation.

The **nucleus** or **germinal vesicle** is a large spherical body which usually occupies an eccentric position in the yolk. Its structure is that of an ordinary cell-nucleus, viz. it consists of a reticulum or karyomitome the meshes of which are filled with karyoplasm. Connected with, or embedded in, the reticulum there are a number of chromatin masses or chromosomes, which may present the appearance of a skein or may assume the form of rods or loops. The nucleus is enclosed by a delicate nuclear membrane, and contains in its interior a well-defined nucleolus or germinal spot.

FIG. 57.—A human ovum stained with Mallory's aniline blue. $\times 600$. Drawn from a specimen lent by Professor Arthur Thomson, University of Oxford.



THE COVERINGS OF THE OVUM

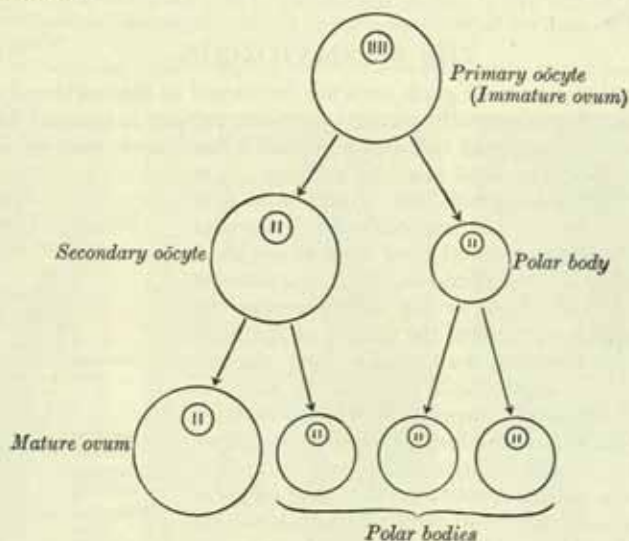
The **zona pellucida** or **zona striata** (fig. 57) is a thick membrane, which, under the higher powers of the microscope, is seen to be radially striated. Between it and the cytoplasm of the ovum there is a narrow *perivitelline space*, filled with fluid, in which the polar bodies are seen lying after their extrusion from the ovum.

The **corona radiata** (fig. 57) consists of two or three strata of radially arranged cells. These consist of the cells of the cumulus ovaricus which adhere to the outer surface of the zona pellucida when the ovum is set free from the vesicular follicle. The cells of the innermost layer are columnar in shape, and send delicate processes through the zona pellucida, thus giving the latter a striated appearance.

THE MATURATION OF THE OVUM

Before an ovum or primary oöcyte can be fertilised, it must undergo a process of *maturation or ripening*. This consists of a preliminary stage of growth during which the ovum increases greatly in size, followed by the process of *meiosis* (p. 5) which comprises first a heterotypical and then a homotypical division.

FIG. 58.—A diagram showing the reduction in number of the chromosomes during the maturation of the ovum. The first division is heterotypical, the second homotypical.



During the stage of growth, changes occur both in the nucleus and in the cytoplasm. The changes in the cytoplasm result in a great increase in the size of the cell. Its metabolic processes become extremely active, and a store of nourishment is accumulated which is necessary for the supply of the ovum during the early stages of its development. The essential feature of the metabolic activity is the *formation of deutoplasm*, but at the same time the amount of protoplasm increases, and the mitochondria become much more numerous.

The changes in the nucleus affect chiefly its chromatin content and they have, to a large extent, been described already (p. 5). It will be remembered that the number of chromosomes found in the nucleus is constant for all the cells in an animal of any given species, and in man the number is forty-eight. This applies not only to the somatic cells but to the oögonia and the primary oöcytes also. In the latter two of the chromosomes possess distinguishing features and are known as the *x-chromosomes*. During the conjugation of the chromosomes in the prophase the *x-chromosomes* pair together.

Having passed through its period of growth, the primary oöcyte is now ready to undergo its first meiotic division. Near its upper pole the paired chromosomes arrange themselves in an equatorial plate with reference to the spindle, which is placed radially. The chromosomes separate and one member of each pair passes centrally, while the others pass outwards, forming a projection at the upper pole of the ovum, which becomes separated off to form the *first polar body*. The division of the cytoplasm, unlike the division of the nucleus, is unequal, and the polar body only carries with it a small part of the cytoplasmic content of the ovum. Following this reductional division the nucleus of the larger cell, which is now a *secondary oöcyte*, is not reconstituted before the cell again divides. Its chromosomes rearrange themselves in an equatorial plate at the upper pole of the cell, preparatory to the second meiotic division. The ovum is liberated from the vesicular follicle at this stage. In man as in most mammals the second meiotic division is completed in the uterine tube and probably only after fertilization.* In this division the chromo-

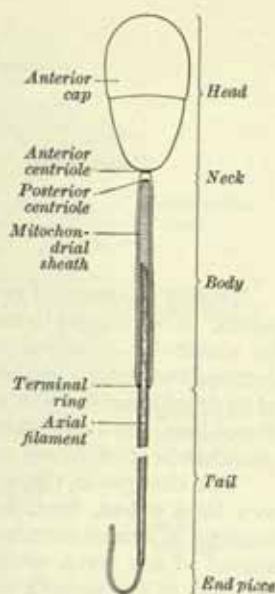
* E. Allen, J. P. Pratt, Q. U. Newell and L. J. Bland, *Contr. Embryol. Carneg. Instn.*, 12, 1930; W. J. Hamilton, *J. Anat. Lond.*, 78, 1944.

somes, already reduced to half the somatic number, split longitudinally and the division of the nucleus is equal but again the cytoplasm divides unequally so that a *second polar body* is formed (fig. 58). The larger cell, which has lost but little of its cytoplasm, is the *ovum* and lies within the *zona pellucida*, together with the two polar bodies, or three, if the first has succeeded in dividing, as it does in some species. The chromosomes of the ovum lose their identity at fertilisation and form a reticulum, constituting the *female pronucleus*. At this stage the mature ovum is characterised (1) by the number of its chromosomes, which is just one-half of the typical number for the somatic cells of the species, (2) by its great size and the large amount of cytoplasm relative to the size of the nucleus, and (3) by the presence of the deutoplasm.

THE SPERMATOZOÖN

The spermatozoa or male germ cells are developed in the testis and are present in enormous numbers (normally 50,000 to 150,000 per μl) in seminal fluid.* Each consists of a small flagellated cell and possesses a *head*, *neck*, *body* or *middle piece*, and a *tail* (fig. 59). The head is about 4μ long. It is ovoid, but is flattened near its free extremity so that when viewed in profile it is pear-shaped. It consists mainly of the nucleus covered by a layer of modified protoplasm which is divided into two parts, the *anterior cap* or *acrosome* and a *posterior cap* or *postnuclear cap* which meet one another about the middle of the head (fig. 60A and B). The neck is about 0.3μ long, slightly constricted and the most fragile part. At its junction with the head and body respectively are the anterior and posterior centrioles, the former consisting of three basal granules. Traversing the neck, body and tail is a core of fibrils which constitutes the *axial filament* and this is probably the main element responsible for the motility of the cell. The axial filament in the neck consists of three bundles of fibrils, each associated with one of the basal granules in the anterior centriole. The body is cylindrical in shape and about 4μ long. At its junction with the tail is a *terminal ring*. The fibrils of the axial filament, in the body, are arranged as two concentric cylinders each of 9 fibrils around a central pair of fibrils (fig. 60D). Surrounding them is a lipid-rich spiral sheath, believed to be derived from the mitochondria and therefore termed the *mitochondrial sheath* (fig. 60B and C). In the tail which is about 37μ long, the axial filament is composed of a central pair of fibrils surrounded by a cylinder of 9 fibrils (fig. 60C). These are covered in most of its length by a thin protoplasmic envelope beyond which the fibrils project freely as the *end piece*.

FIG. 59.—Diagram of a spermatozoön.



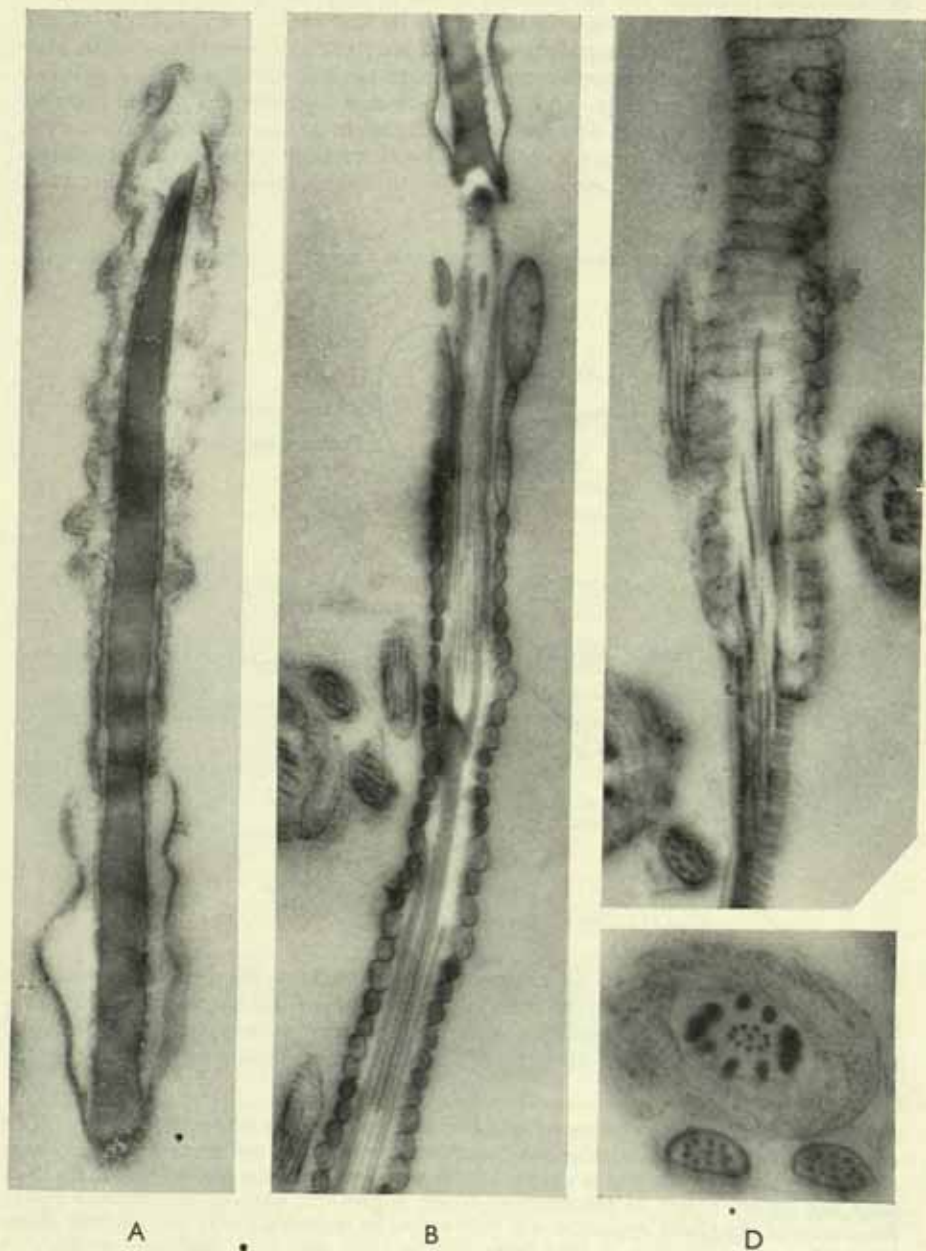
Spermatozoa show no independent motility in the male genital tract but display it immediately after ejaculation. In addition to the independent motility due to a continual rhythmic spiral movement of the tail, dense sperm suspensions show a wave-like motion of the sperms which tend to be orientated against the current of the fluid. The sperms undergo a process of ripening in the male genital tract which is probably continued in the female genital tract. Associated with the ripening in the male genital tract in some mammals is the backward migration along the surface of the head and middle piece of the sperm of a small mass of cytoplasm termed the *kinoplasmic droplet*. This ultimately disappears. By their free movement spermatozoa ascend from the vagina into the cavity of the uterus, and from the latter into the uterine tube. Their survival in the female passages, however, is limited to about one to two days.

The spermatozoa are developed from the primordial germ-cells (p. 211) embedded in the testes, and the stages of their development are very similar to those of the maturation of the ovum. The primary germ-cells undergo division and produce a number of cells termed *spermatogonia*.

* For details see T. Mann, *Biochemistry of Semen*, London, 1954.

FIG. 60.—Electron micrographs of sections of ram spermatozoa : (A) Longitudinal section of the head seen in profile ; the anterior part is covered by the acrosomal cap. $\times 20,000$; (B) Longitudinal section of the posterior part of the head, neck and anterior part of the middle piece. The axial filament is seen surrounded by the mitochondrial sheath which has been cut across. The oval body at the right side of the neck may be a centriole. $\times 20,000$; (C) A partly tangential section of the posterior part of the middle piece showing the spiral form of the mitochondrial sheath. In the lower part is the beginning of the tail piece in which the axial filament is surrounded by a tape-like helix. $\times 25,000$; and (D) Transverse section of (i) the middle piece showing the two central fibrils surrounded by nine peripheral fibrils, each of which is believed to be composed of two closely adjacent fibrils. These fibrils are themselves surrounded by nine larger fibrils which are seen in longitudinal section in (B), outside these is the mitochondrial sheath (ii) the tail filament surrounded by a dense membrane. $\times 50,000$.

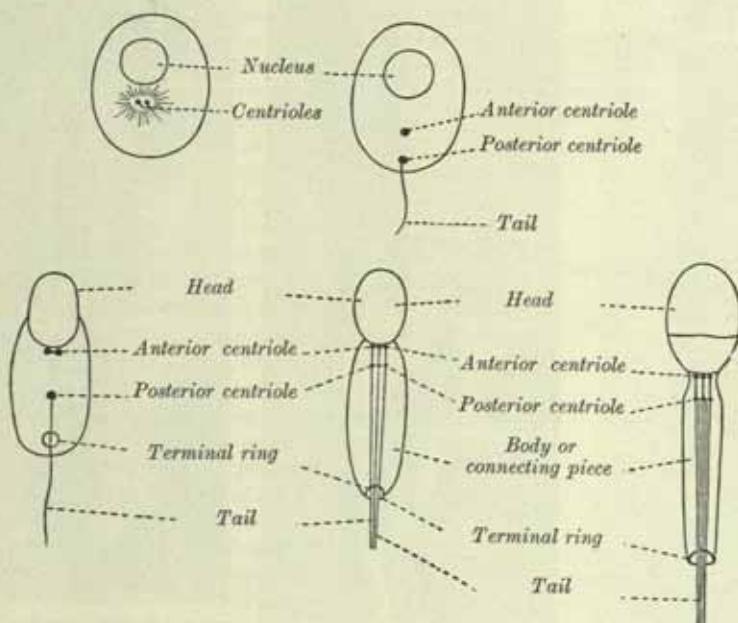
Prepared and kindly supplied to the editors by Miss S. Fitton Jackson.



After a number of mitoses the spermatogonia enter on a resting phase and gradually change, without further division, into *primary spermatocytes*. During this period the cell body enlarges, the mitochondria increase in number, and the centrosome, previously difficult to identify, becomes easy to recognise. The nuclear changes of the first meiotic division have already been described (p. 5), but it is necessary to add that the chromosomes of the primary spermatocyte include two sex chromosomes, one of which, the *x*-chromosome, is identical with the sex chromosomes of the oögonia; the other is very diminutive and is termed the *y*-chromosome. During conjugation the *x*- and the *y*-chromosomes become mated. It should be stated that many authorities have denied the existence of a *y*-chromosome in man, and believe that during conjugation the *x*-chromosome does not mate. However, Severinghaus * has brought forward strong presumptive evidence that the *y*-chromosome does in fact exist and claimed that the sex chromosomes represent the karyosomes of the nucleus of the spermatogonium.

The primary spermatocyte now undergoes its first meiotic division, giving rise to two apparently equal *secondary spermatocytes*, each of which possesses one-half of the number of chromosomes which is typical for the species. When division occurs, the mated *x*- and *y*-chromosomes separate and pass to opposite poles of the spindle, so that one becomes included in one secondary spermatocyte, and the other in the other. After a brief resting phase each secondary spermatocyte undergoes a second meiotic division, forming two *spermatids*.

FIG. 61.—The transformation of a spermatid into a spermatozoön. Diagrammatic. (Modified from Meves.)



Division affects the *x*- and *y*-chromosomes as well as the others, and of the four spermatids which result from the division of each primary spermatocyte, two possess *x*-chromosomes and two possess *y*-chromosomes, while all four contain half of the number of chromosomes which is typical for the species.

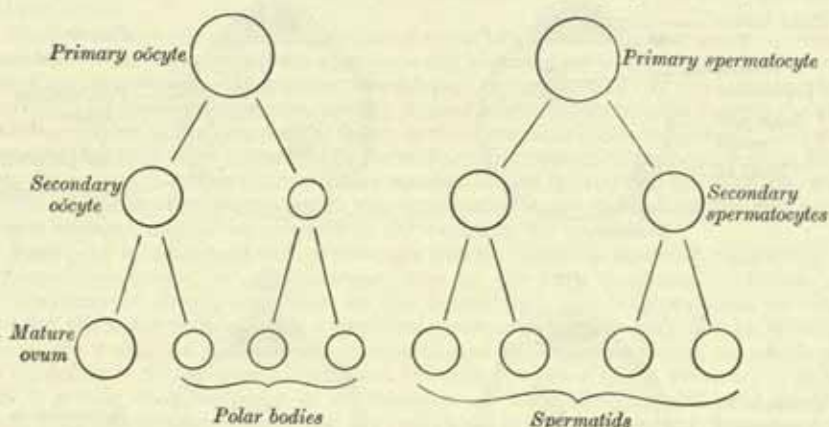
The spermatids are converted without further division into spermatozoa. The complicated morphological changes occurring at this stage are termed *spermateleosis* (fig. 61). The anterior cap is derived from the Golgi apparatus which flattens itself over the anterior part of the nucleus which forms the head of the spermatozoön. Remnants of the Golgi apparatus are believed to be included in the kinoplasmic droplets. The two centrioles, at first lying side by side, alter their positions so that one

* A. E. Severinghaus, *Amer. J. Anat.*, 70, 1942.

comes to be placed deeper than the other. According to one view the deeper centriole becomes the anterior centriole of the neck whilst the axial filament grows out of the superficial centriole which divides to give the posterior centriole of the neck and the terminal ring. Another view is that the axial filament is derived from the two centrioles conjointly, the deeper one of which becomes the posterior centriole of the neck whilst the more superficial becomes ring-shaped and migrates to the junction of the body and tail to become the terminal ring. According to this view the centriolar nature of the so-called anterior centriole of the neck is doubtful but the granules of which it is composed are present in the early spermatid and connected with the anterior centriole.* The mitochondria collect around the axial filament to form the spiral sheath of the body and the cytoplasm forms the investing sheath of the body and tail.

On comparing the development of the spermatozoön with the maturation of the ovum or primary oöcyte (fig. 62) it will be observed that the primary spermatocyte gives rise to two secondary spermatocytes, and the primary oöcyte to the secondary

FIG. 62.—A scheme showing the analogies in the process of maturation of the ovum and the development of the spermatids (young spermatozoa).



oöcyte and the first polar body; the two secondary spermatocytes give origin to four spermatozoa, and the secondary oöcyte and first polar body to four cells, the mature ovum and three polar bodies. In the development of the spermatozoön, and in the maturation of the ovum, there is a reduction of the nuclear chromosomes to one-half of those present in the parent cell, and in each case the reduction is preceded by a process of conjugation of the chromosomes. But here the similarity ends, for it must be noted that the four spermatozoa are of equal size, and each is capable of fertilising a mature ovum, whereas the three polar bodies are much smaller than the mature ovum, are incapable of further development, and may be regarded as abortive ova.

THE FERTILISATION OF THE OVUM

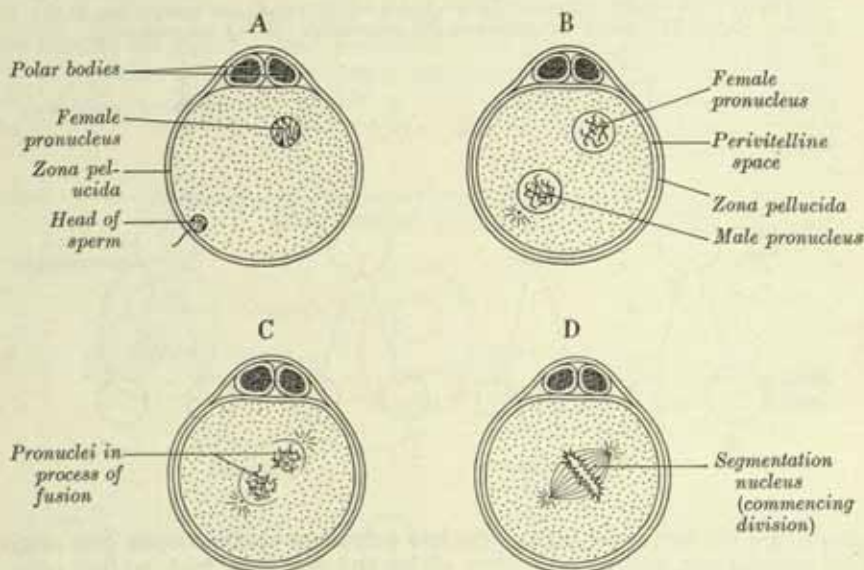
Fertilisation consists of the union of a spermatozoön with an ovum (fig. 63), and this takes place in the lateral or ampullary part of the uterine tube.

In mammals only one spermatozoön usually succeeds in piercing the vitelline membrane and entering the ovum. Immediately following penetration by the sperm a space—the *perivitelline space*—appears between the *zona pellucida* and the vitelline membrane. Once within the ovum the head and neck of the sperm become detached from the middle piece and tail, which soon lose their identity. The ultimate fate and significance of these two parts in fertilisation is unknown. The second maturation division, initially in metaphase, is completed after the entry of the spermatozoön, and the second polar body is extruded into the perivitelline space. At the same time* the head of the spermatozoön swells and becomes the *male pronucleus*.

* J. B. Gatenby and H. W. Beams, *Quart. J. Micr. Sci.*, 78, 1935.

The male and female pronuclei approach and come into contact with each other and lose their nuclear membranes. The degree of fusion of the two nuclei to form a single *segmentation nucleus* varies in different animals. As a rule their chromosome groups remain separate in the prophase. Meanwhile a centrosome, believed to contain the anterior centriole of the sperm appears between the groups, divides and forms the first segmentation spindle on the equator of which the chromosomes arrange themselves. The chromosomes on the spindle now constitute the typical number for the species; one half of this number has been derived from the ovum and the other half from the spermatozoön. These chromosomes then divide and retreat from the equator in opposite directions and the cytoplasm of the ovum segments into two daughter cells or blastomeres of nearly equal size. The next stage, viz., the segmentation of the ovum has now begun.

FIG. 63.—The process of fertilisation in a mammalian ovum. Diagrammatic. (After Sobotta.)



The female pronucleus and second polar body, shown in A, are only formed after fertilisation.

In many mammals, and probably also in man, there would appear to be an excess of yolk in the ovum at fertilisation and a quantity of deutoplasm is extruded into the perivitelline space immediately prior to the first segmentation. This process is termed *deutoplasmolysis*.

The rôle of the chromosomes.—It is generally believed that the mature ovum contains within itself all the materials essential for the formation of a new being, and in the lower forms at least may produce such, when its potential energy is converted into free energy by suitable mechanical or physico-chemical means. Loeb and others were able to imitate the process of fertilisation in sea-urchins, frogs, etc., by altering the osmotic pressure of the unfertilised ovum.

Reference has already been made to the fact that the spermatozoa, in equal numbers, contain either an x- or a y-chromosome, and that the mature ovum contains one x-chromosome. If an ovum be fertilised by a spermatozoön containing an x-chromosome, the cells of the embryo will each contain two x-chromosomes and the embryo will be female, but if an ovum is fertilised by a spermatozoön containing a y-chromosome, the cells of the embryo will each contain one x- and one y-chromosome and its sex will be male.

This, however, is not the only factor involved in the determination of sex. The theory advanced is that the chromosomes contain materials which initiate and control, by chemical means, the processes that lead to the development of the various tissues and their individual peculiarities. The establishment of a sex-difference is therefore, in the first instance, dependent on a specialised chromosome, but the

development of the sexual features at a later stage results from the presence of specialised chemical substances in the chromosomes.

The polarity of the fertilised ovum is fixed at a very early stage, and it would appear that, in many animals at least, the plane of bilateral symmetry is determined by the line of entry of the spermatozoön. Nevertheless it must be remembered that the cells derived from the ovum by its early segmentations are totipotent. Consequently a fertilised ovum may later divide into two equal parts, each of which may go on to form a complete embryo (*uniocular twins*), although under normal conditions it will only give rise to a single embryo.

Heredity and Human Genetics.*—Before the chromosomes had been discovered, Father Gregor Mendel (1822-1884) had postulated, as the basis of his explanation of the phenomena of heredity, the presence of certain factors in the sex cells which have since been termed *genes*. The study of heredity, from the genetic aspect, has become greatly intensified since the discovery of the chromosomes and the investigation of their behaviour. As a result it is now widely held that the genes fore-shadowed by Mendel do in fact exist: that they are borne as ultramicroscopic particles by the chromosomes in all the cells of the body: and that they are transmitted from parents to offspring in the chromosomes of the sperm and the ovum.

Each chromosome carries a number of genes *arranged in a linear series* and the 48 chromosomes of man constitute 23 genetically homologous pairs (or *autosomes*) and a pair of *sex chromosomes*, one member of each pair being paternal and the other maternal in origin. Corresponding genes, usually termed *allelomorphs*, occupy exactly the same position relative to the centromere (p. 5) in their respective chromosomes. It is to be observed that, although in the female the two sex chromosomes are homologous, in the male the *x*- and *y*-chromosomes differ notably in size (p. 62) and the *x*-chromosome carries a number of genes which are not represented in the *y*-chromosome and which, on this account, cannot be essential to the ordinary life processes.

Each gene is concerned with at least one specific character and with regard to it the corresponding genes, or *allelomorphs*, may be (1) both *dominant*, in which case the character is clearly expressed in the individual; (2) both *recessive*, in which case the character is present in a modified form and may or may not be recognisable in the individual; or (3) one dominant and the other recessive, in which case the character is always clearly expressed, because *the power of the dominant to express itself is greater than the power of the recessive*. If both *allelomorphs* have the same value, either dominant or recessive, the individual is said to be *homozygous* in respect of this particular character, but if one is dominant and the other recessive, the term *heterozygous* is employed.

The particular character associated with a recessive gene may be, and often is, more conspicuous than the character associated with its corresponding dominant. For example, red hair is associated with a recessive gene, and red-haired individuals possess both *allelomorphs* concerned in the recessive state, whereas dark or fair-haired individuals have one (*heterozygotes*) or both (*homozygotes*) of the same genes in the dominant condition. In the notation of Genetics a red-haired individual is designated 'rr', whereas dark or fair-haired individuals are 'RR' (*homozygotes*) or 'Rr' (*heterozygotes*), dominants being indicated by capital letters and recessives by small letters.

In certain rare diseases which are known to be hereditary, e.g. Friedreich's ataxia, the gene concerned is recessive. The incidence of this disease is so low that the bulk of the population must be *homozygotes* with regard to this particular character, both genes being 'contra'. As the subjects affected rarely marry, the disease occurs sporadically in the offspring of healthy parents. *Both* such parents must be *heterozygous* in this respect, as it is only in such an event that the two recessive genes have a chance (1:3) of coming together. Careful investigation into the family history in these cases has shown that the disease has occurred amongst the forebears of both parents—usually of the same family—and on this account intermarriage of first cousins or more distant relatives in affected families should always be discountenanced, for there is, as yet, no known method of distinguishing between an unaffected *homozygote* and a *heterozygote*.

As each chromosome contains a large number of genes, neighbouring genes in the linear series will always tend to be incorporated in the same chromosomes, whether they are affected by the 'cross-over' (p. 6) or not. The corresponding characters will therefore tend to appear together in the same individual and they are said to be *linked*.

* A full discussion of this subject would be out of place in a textbook of Human Anatomy and nothing more than the merest outline of the elementary principles of Genetics is included. Those who wish to go further into the subject should consult *Genetics for Medical Students*, by E. B. Ford, London, 1948; or *An Introduction to Medical Genetics*, by J. A. Frazer Roberts, Oxford, 1940.

Certain hereditary diseases, e.g. Huntington's chorea, do not present recognisable signs or symptoms before the average age for marriage and this makes it difficult to advise members of affected families as to the desirability or otherwise of marriage. Definite knowledge of other easily recognised characters with which these diseases had been proved to be linked would enable the medical history of such individuals to be predicted with some degree of certainty. Unfortunately our present knowledge of linkage in the human subject is still very scanty and much additional data must be collected before the science of Eugenics can exercise a really effective influence on future generations.

In man the best evidence, hitherto available, of the occurrence of linkage is found in connexion with the sex chromosomes and especially with the *x*-chromosome. In addition to genes which have an important influence on the determination of sex, the sex chromosomes—especially the *x*-chromosomes—carry genes which are concerned with non-sexual characters. These genes therefore are *sex-linked* and they include those concerned with the disease of hæmophilia, those concerned with one of the commoner varieties of colour-blindness, and those concerned with a number of rare diseases of the skin, of the eyes and of the nervous system.

The disease hæmophilia, which is operated by a recessive sex-linked gene, affects males only despite the fact that it is transmitted by the female. The mother of a hæmophiliac must be a heterozygote, for females are never affected by the disease but are nevertheless able to transmit it to their male offspring. The father of a hæmophiliac is commonly healthy in this respect, *but his y-chromosomes do not carry any corresponding gene*. The female offspring will have an equal chance of being homozygous (and incapable of transmitting the disease) or heterozygous like their mother, while the male offspring have an equal chance of being normal or of being hæmophiliacs. The marriage of a normal male with a heterozygous female and the possible varieties of offspring may be expressed as follows:

$$x^{H}y + x^{H}x^{h} = x^{H}x^{H} : x^{H}x^{h} : x^{H}y : x^{h}y.$$

On the other hand when a hæmophiliac man ($x^{h}y$) marries a healthy woman ($x^{H}x^{H}$), i.e. a homozygote 'contra' in this respect, his sons will not be affected ($x^{H}y$), but his daughters will all be heterozygotes ($x^{H}x^{h}$). The disease therefore skips that generation but it will reappear in the male offspring (1:1) of the daughters. The only possible marriage which could give rise to a hæmophiliac female is one between a hæmophiliac man and a heterozygous woman. Such marriages must be uncommon, but, on the assumption that they do occur, the hæmophiliac female offspring are never viable and no record exists of a living female hæmophiliac.

THE SEGMENTATION OF THE FERTILISED OVUM

Only a few specimens of the earliest stages of development of the human ovum under normal conditions have been studied.* In addition a few mature human ova, fertilised in tissue culture media, have been obtained in the 2-cell and 3-cell stages.† The following account is based on these specimens and supplemented, where necessary, by reference to the early development of other mammals and especially the Macaque monkey.‡

Fertilisation occurs, as in most mammals, at the outer end of the uterine tube. After completion of the 2nd maturation division the ovum divides into two cells or blastomeres of approximately equal size. The only human 2-cell stage so far recorded was recovered from the middle of the uterine tube, 60 hours after a fertile mating (fig. 64). By repeated division and subdivision of the blastomeres a mass of cells, termed the *morula*, is formed. During these changes the intense activity of the cytoplasm of the cells is evidenced by the constant streaming of their contained granules. The individual cells do not remain motionless, but restlessly alter their positions relative to one another and reorientate themselves within the zona pellucida, for they are still in fact individual units and have not yet resolved into tissues. The human ovum is believed to enter the uterus at about the 12-cell morula stage and about 72 hours after fertilisation. Four human morulae of 5 to 12 blastomeres, all of which, however, are believed to have been abnormal, have been recovered from the uterus on the fourth day after presumed ovulation and fertilisation.

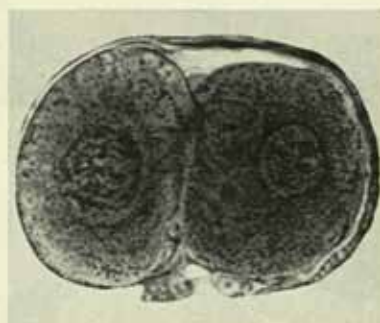
* A. T. Hertig, J. Rock, E. C. Adams and W. J. Mulligan, *Contr. Embryol.*, Carneg. Instn., 35, 1954.

† M. F. Menkin and J. Rock, *Anat. Rec.*, 100, 1948.

‡ G. L. Streeter and C. H. Heuser, *Contr. Embryol.*, Carneg. Instn., 29, 1941.

Before segmentation occurs the amount of cytoplasm in the fertilised ovum is great out of all proportion to the size of the nucleus, and the initial divisions which result in the formation of the morula have the effect of reducing the disproportion

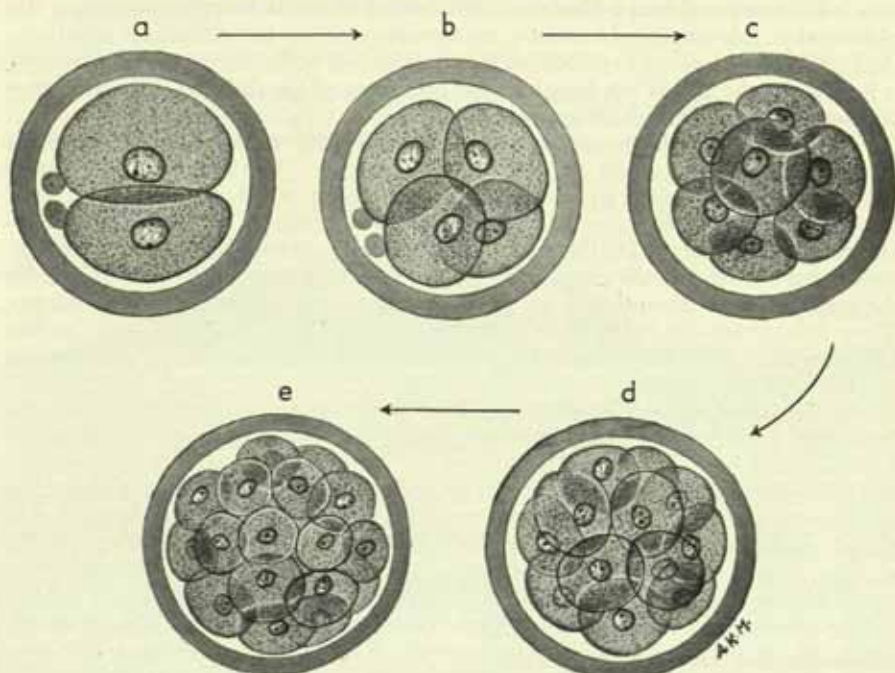
FIG. 64.—A two-cell human ovum recovered from the uterine tube. A polar body is seen at either end of the cleavage plane. $\times 330$. (A. T. Hertig, J. Rock, E. C. Adams and W. J. Mulligan, *Contr. Embryol.*, Carneg. Instn., 35 1954).



until the cytoplasm bears to the nucleus the relationship which obtains in the average somatic cells of the species.

During the earlier divisions two different groups of cells emerge. Of these, the one will form the embryo and the other will form the nourishing and protective membranes by which it is surrounded. The former divide more slowly and retain to a high degree the potencies of the totipotent ovum; the latter divide more rapidly

FIG. 65.—The first stages of the segmentation of a mammalian ovum. Semi-diagrammatic. (After a drawing by Allen Thomson.)



Note that the zona pellucida remains intact from the two-cell stage (a) to the morula stage (d and e) and that as the cells increase in number they become smaller in size.

and suffer a marked reduction in potency as they become differentiated into *trophoblast*.

Before the zona pellucida disappears, fluid, either secreted by the trophoblastic cells or derived from the uterine lumen, begins to accumulate within the morula.

The intercellular spaces enlarge and coalesce to form a single fluid-filled cavity, the *blastocoele*. This is bounded by the trophoblast cells and occupies the whole of the interior except at one place where a clump of cells, termed the *inner cell mass* or *formative mass* (figs. 66 and 67) projects into the cavity. This represents the residue of totipotent cells, some of which are destined to form the embryo. The ovum has

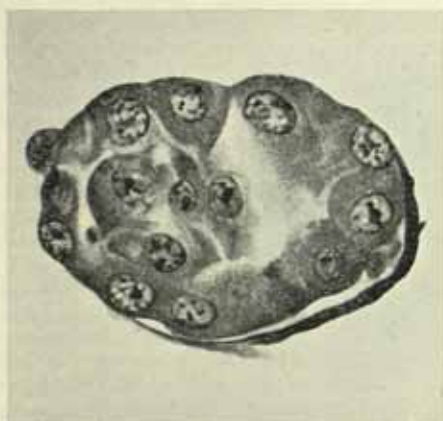


FIG. 66.—Section of a 58-cell human blastocyst recovered from the uterine cavity showing the zona pellucida, trophoblast and inner cell mass. $\times 510$. (A. T. Hertig, J. Rock, E. C. Adams and W. J. Mulligan, *Contr. Embryol. Carneg. Instn.*, **35**, 1954).



FIG. 67.—Section of a 107-cell human blastocyst recovered from the uterine cavity. The mural and polar trophoblastic cells and the inner cell mass can be distinguished. $\times 550$. (A. T. Hertig, J. Rock, E. C. Adams and W. J. Mulligan, *Contr. Embryol. Carneg. Instn.*, **35**, 1954).

now been converted into a *blastocyst*. Of a total of about 60 cells composing the blastocyst at this stage, only about 5 are formative cells; the remainder constitute the flattened trophoblastic epithelium forming the wall of the vesicle. The blastocyst is formed by the end of the fourth or the beginning of the fifth day after ovulation and lies free in the uterine cavity.

The zona pellucida disappears during the fifth day after ovulation by which stage the blastocyst is about 134μ in average diameter. The cells of the formative cell mass have multiplied and form an irregular clump which has insinuated itself into the wall of the blastocyst and is flanked by trophoblast. Of the 107 cells constituting the blastocyst at this stage, 69 are mural trophoblast cells. Of the remainder 8 are large cells constituting the formative mass and are destined to form the embryo. The remaining 30 are *polar trophoblast* cells and lie around its margin. They later cover the outer surface of the formative mass while its deep surface becomes lined by a single layer of polyhedral cells which constitute the primary endoderm (fig. 67).

In the latter part of the sixth day after fertilisation the trophoblast over the formative mass adheres to the uterine mucosa, exerting a histolytic action on its lining epithelium. As it engulfs the uterine tissue the trophoblast cells in this situation divide with such rapidity that all trace of cellular definition is lost and the formative mass becomes covered with a multinucleated mass of cytoplasm, termed the *plasmodial trophoblast*, which burrows into the stratum compactum of the uterine mucosa. As the blastocyst becomes more deeply embedded, the remainder of its trophoblastic wall undergoes a similar change, but, at a slightly later stage, cellular definition reappears on the inner or embryonic surface of the plasmodial trophoblast. Thereafter the wall of the blastocyst consists of an inner cellular layer, the *cyto-trophoblast*, covered on its outer surface with plasmodial trophoblast, which is thickest over the formative mass, i.e. at the area of deepest penetration or *embryonic pole*, and thinnest over the area most recently embedded or *abembryonic pole*.

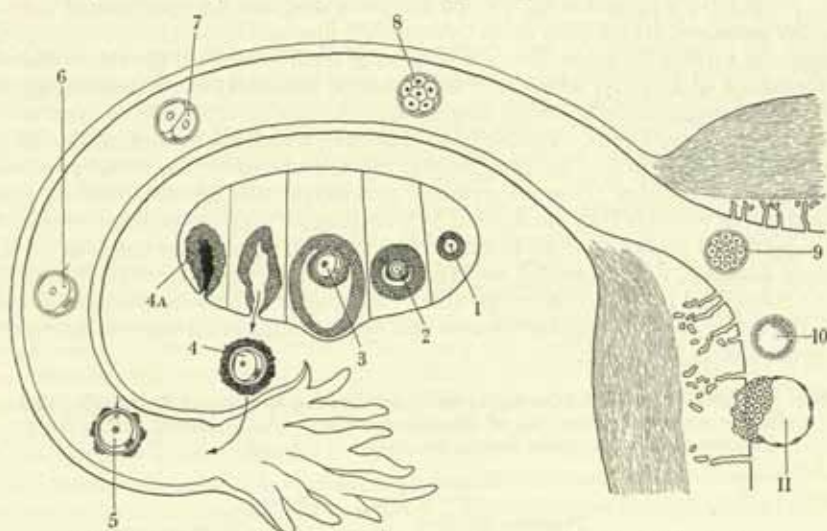
The *site of implantation* is normally on the posterior wall of the uterus, nearer to the fundus than to the cervix, and may be in the median plane or to one or other side.

The youngest implanting human ovum hitherto reported and described in detail*

* J. Rock and A. T. Hertig, *Contr. Embryol.*, Carneg. Instn., **31**, 1945.

shows an early stage in the process of embedding. The trophoblast over the formative mass displays an extensive development of plasmodium, which has destroyed a

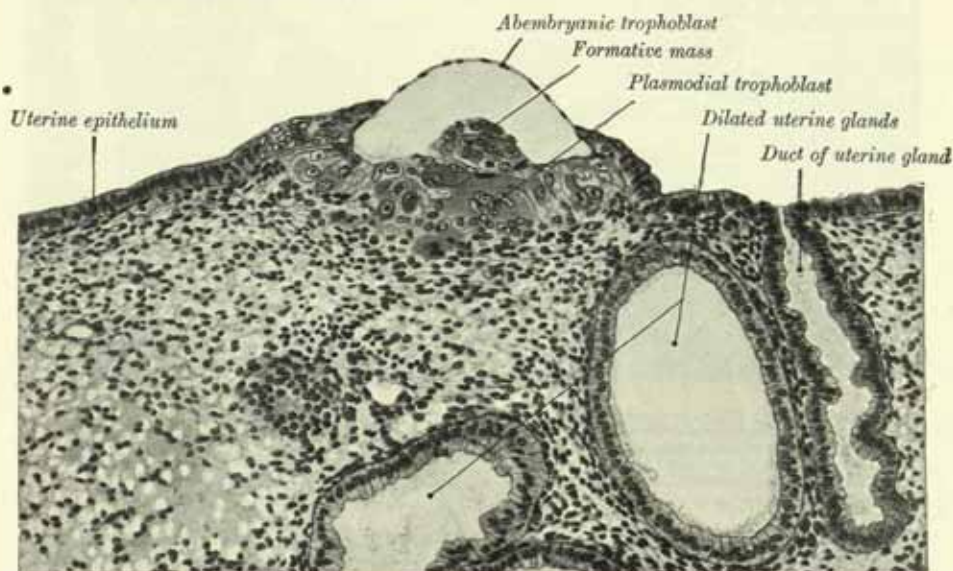
FIG. 68.—Diagram (based on Dickinson) to show the stages in the maturation and development of an ovum which becomes fertilised, up to the point when the process of implantation, or embedding, is begun.



(1) and (2) Early stages in ovary. (3) Enlargement of ovum and ovarian follicle: formation of first polar body. (4) Mature ovum, surrounded by zona pellucida and corona radiata, extruded from ovary by rupture of ovarian follicle: formation of second polar body. (4A) Corpus luteum, early stage. (5) Fertilisation of ovum in ampullary part of uterine tube: male and female pronuclei present. Note the tail of the spermatozoon outside the zona pellucida. (6) Segmentation nucleus. (7) Two-cell stage. Note diminished size of cells. (8) Eight-cell stage. (9) Morula. (10) Blastocyst free in uterine cavity. Note formative mass. (11) Zona pellucida has disappeared: trophoblast has thickened over embryonic pole, and implantation process has begun.

patch of uterine epithelium and the underlying stroma (fig. 69). The blastocyst,

FIG. 69.—A human ovum (Carnegie, 8020), fertilisation age 7-7½ days, in process of embedding in the uterine mucosa. (J. Rock and A. T. Hertig, *Am. J. Obst. and Gynec.*, 44, 1942, and 47, 1944.) ($\times c. 150$.)



In the actual specimen the abembryonic trophoblast had collapsed on the formative mass but, for purposes of clarity, it has been shown projecting into the uterine cavity.

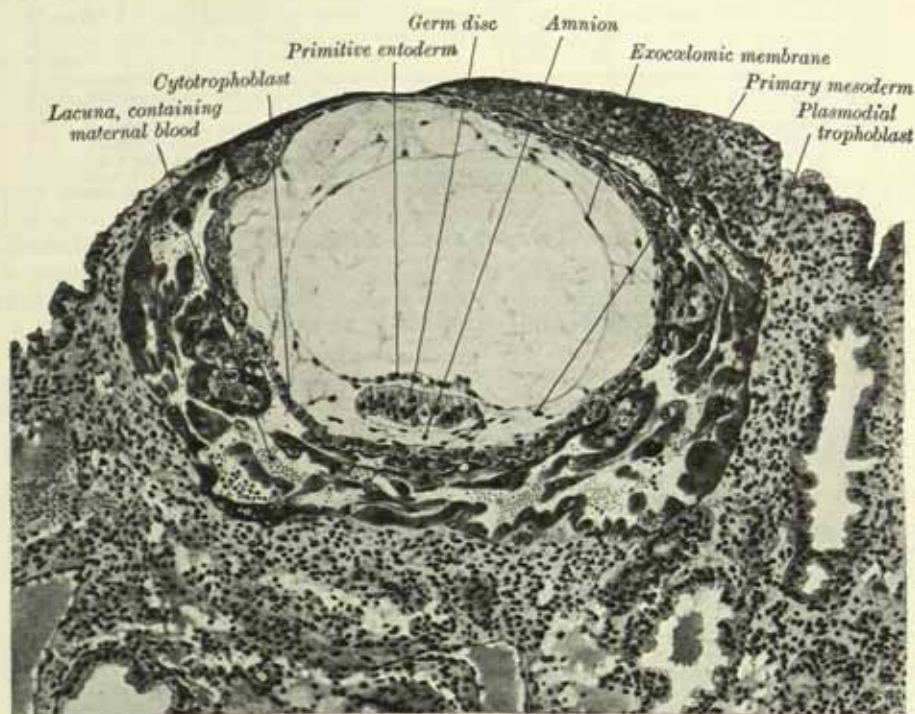
Drawn from a photomicrograph kindly given to the Editor by Dr. A. T. Hertig.

however is not completely embedded and a portion of its wall, at the opposite pole to the formative mass, still projects into the uterine cavity. The fertilisation age of this

ovum is believed to be $7\frac{1}{2}$ days. In a slightly older ovum * ($9\frac{1}{2}$ days) the blastocyst is completely embedded. The plasmodial trophoblast has undergone further proliferation and now covers the wall at the opposite pole to the formative mass with a thin layer. Irregular lacunar spaces are present in the plasmodium and they communicate with eroded maternal veins. The formative mass now consists of a thick plate of large, irregularly arranged cells, termed the *germ-disc*, and a single-layered sheet of *primitive entoderm*, which intervenes between the disc and the blastocyst cavity. On its opposite surface the germ-disc is in process of separation from the trophoblast by the formation of a cavity, which will soon become the *cavity of the amnion* (fig. 72).

In the immediately succeeding stages the blastocyst cavity becomes lined with a thin layer of flattened cells, mesothelial in character, which are in continuity with the primitive entoderm around its margins (fig. 72, A) and enclose the *primary yolk-sac*. It is uncertain whether these are primary mesoderm cells derived from the cytotrophoblast or whether they are formed by an extension from the primitive entoderm—the condition known to exist in the rabbit, dog and some other mammals. The primary yolk-sac, formed in this way (fig. 72, A and B), appears to be designed to meet a functional need and serves to 'filter' the fluid which the trophoblast absorbs from the cytolysis of the uterine mucosa and makes available for the nourishment of the germ disc at this stage.

FIG. 70.—A human ovum (Carnegie, 7700), fertilisation age 12–12½ days, embedded in the stratum compactum of the endometrium. (A. T. Hertig and J. Rock, *Contrib. Embryol. Carneg. Instrn.*, 29, 1941.) ($\times c. 105$.)



Compare with fig. 69 and note the development of the lacunae in the plasmodial trophoblast, many of them containing maternal blood. Note that the primary yolk-sac, which is surrounded by the exocoelomic membrane, does not quite fill the blastocyst cavity. The cells of the germ disc are now columnar in shape and form an ectodermal plate.

Drawn from a photomicrograph kindly given to the Editor by Dr A. T. Hertig.

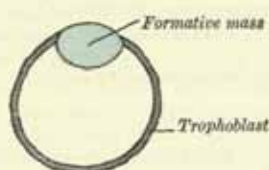
The cells of the germ disc, hitherto arranged in an irregular manner, now dispose themselves in the form of a plate of columnar cells. The cavity between the plate and the overlying cytotrophoblast (fig. 70) soon acquires a thin roof consisting of primary mesoderm derived from the cytotrophoblast and termed the *amnion*. At the same time other mesodermal cells delaminate from the inner surface of the cytotrophoblast and intervene between it and the primary yolk-sac. The wall of the

* J. Rock and A. T. Hertig, *Contr. Embryol.*, Carneg. Instrn., 31, 1945.

sac (often termed the *exocoelomic membrane*) becomes retracted from the wall of the blastocyst, although it usually remains connected to it near the abembryonic pole by strands of mesoderm. Descriptions of several human ova * which have reached this stage* and are already completely embedded in the uterine mucosa are now available.

The ovum depicted in fig. 70 corresponds almost exactly with the stage shown diagrammatically in fig. 72, B. The shell of trophoblast is thickest over the embryonic pole and over the sides of the blastocyst, but is exceedingly thin over the abembryonic pole, the last part to be embedded. It is lined over most of its extent by a single layer of cytotrophoblast and the covering plasmodial trophoblast shows the presence of numerous lacunæ. In several places maternal blood from vessels which have been invaded by the plasmodial trophoblast has found its way into the lacunæ and serves as a new source of nourishment. Within the trophoblastic shell, the cells of the germ-disc, which have now become arranged as a columnar epithelium, constitute the *ectodermal plate* or *disc*. On the one hand they are separated from the cytotrophoblast by the amnion, its cavity and primary mesoderm; on the other, they are in close contact with the primitive endoderm, although a distinct basement membrane forms a sharp line of demarcation. The primitive endoderm consists of a single layer of low cubical epithelium, lining the ventral surface of the germ-disc and forming the roof of the primary yolk-sac, which contains fluid and a certain amount of coagulum resulting from the effects of the process of fixation. The interval between the trophoblast shell, on the one hand, and the primary yolk-sac and the developing amnion, on the other, is occupied by fluid in which are found primary mesoderm cells delaminated or delaminating from the cytotrophoblast, together with a certain amount of coagulum. The trophoblastic wall of the blastocyst

FIG. 71.—A. Early blastocyst.



B. Differentiation of formative mass and development of primary mesoderm.

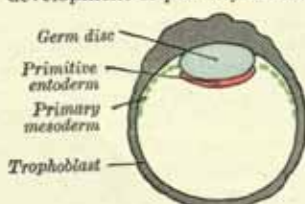
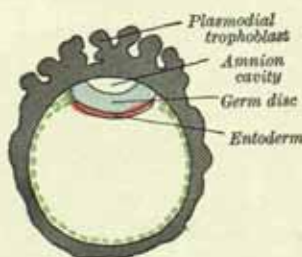
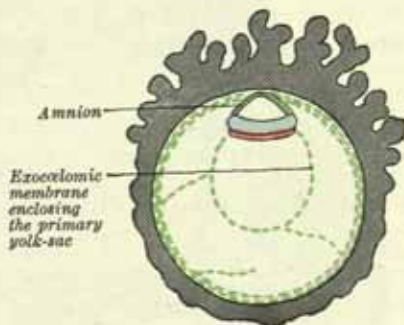


FIG. 72.—A. Formation of amniotic cavity and increased growth of primary mesoderm.



B. Formation of amnion and primary yolk-sac.



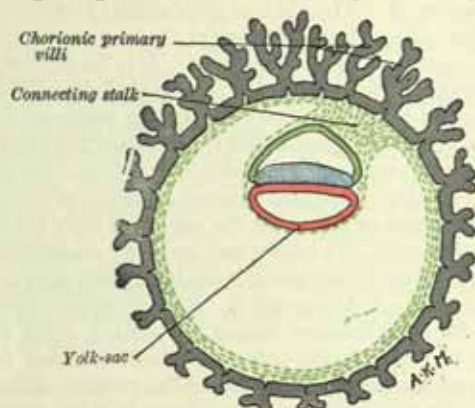
with its lining of primary mesoderm constitutes the *chorion*, and the general cavity of the blastocyst can therefore be termed the *chorionic cavity*.

The cavity of the amnion with its roof and floor constitutes the *amnio-embryonic vesicle*. At first primary mesenchyme connects the chorion to the amnion over a wide area, but with the development and coalescence of clefts in the primary mesoderm to form the extra-embryonic coelom, this attachment soon becomes circumscribed to form a *connecting stalk* in the region of the caudal end of the embryo

* A. T. Hertig and J. Rock, *Contr. Embryol.*, Carneg. Instn., **28**, 1941; and **31**, 1945; J. H. Dible and C. M. West, *J. Anat.*, Lond., **75**, 1941; H. Stieve, *Zeits. fur Mikrosk. Anat. Forsch.*, 1936; P. N. B. Odgers, *J. Anat.*, Lond., **71**, 1937; and F. Davies, *Trans. Roy. Soc. Edin.*, **61**, II, 11, 1944.

(fig. 73). This stalk forms a permanent connexion between the embryo and the chorion and it is the pathway along which the blood-vessels of the embryo later

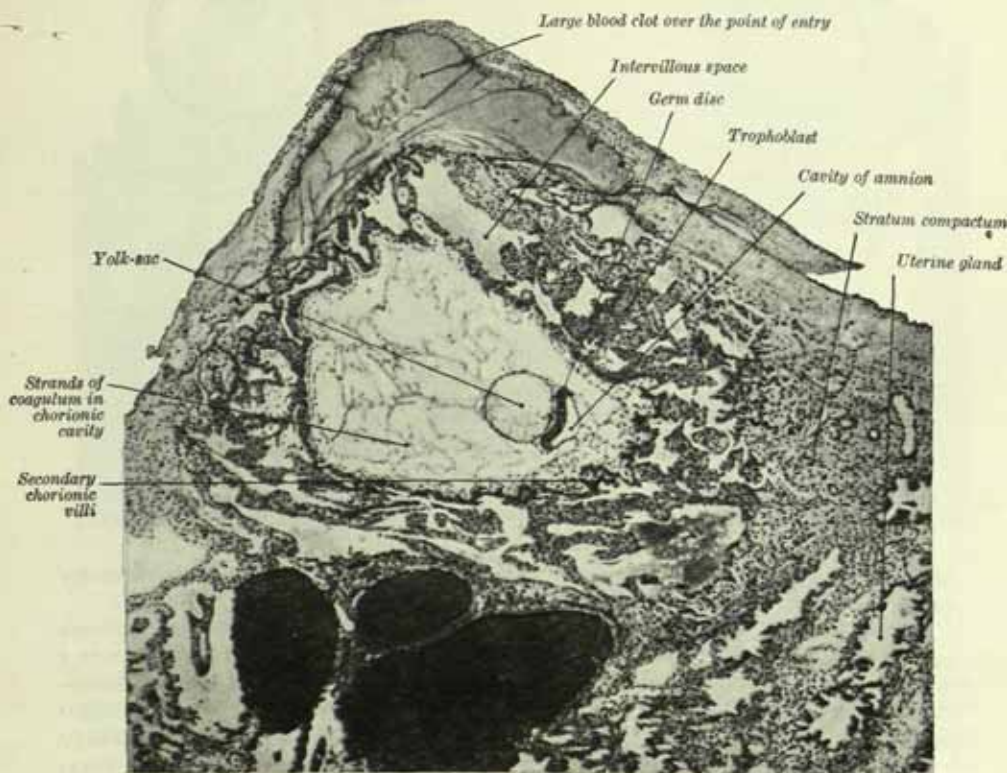
FIG. 73.—The primary yolk-sac has become reduced in size to form the (secondary) yolk-sac, which is covered externally with primary mesoderm. This is the condition found at the end of the second or the beginning of the third week. Compare with fig. 74.



establish communication with those of the chorion. Subsequently it becomes converted into the *umbilical cord*.

While the connecting stalk is being defined, the primary yolk-sac suffers a material reduction in size, the mechanism of which is still obscure, although it seems probable that part of its wall becomes drawn out by the mesodermal strands which anchor

FIG. 74.—A human ovum, embedded in the stratum compactum. Estimated age, 13.5 days. (A. T. Hertig and J. Rock, *Am. J. Obst. and Gynec.*, 44, 1942.) ($\times 35$.)



it to the abembryonic portion of the chorion and then loses its connexion with the rest of the sac. The resultant smaller sac is the definitive yolk-sac (figs. 73 and 74)

and is usually referred to as simply the *yolk-sac*.^{*} Although the wall of the primary yolk-sac consists of a single layer of cells (fig. 70), the wall of the definitive sac is formed by a double layer in later stages (fig. 73). The outer layer is derived from the primary mesoderm but, as already indicated, it is uncertain whether the inner layer owes its origin to the primary mesoderm or to the primitive entoderm. However, it is only the roof of the yolk-sac which is responsible later for the development of the intraembryonic entodermal structures.

In the immediately succeeding stage, of which many examples are available, the chorionic cavity contains two hollow vesicles (the amnio-embryonic and the yolk-sac), covered with primary mesoderm, by which they are connected to the wall (fig. 74). Only the cells where the two vesicles are in contact with each other contribute to the formation of the actual embryo, and it is therefore this region which is termed the *embryonic area* or *shield*. Streeter is of the opinion that the cells included in this area represent the sole derivatives of the germ-disc.

It is noteworthy that of the cells derived from the ovum at this stage only a relatively small number take part in the formation of the embryo, while the vast majority form its covering and nourishing membranes and certain other extra-embryonic structures to be noted later. The cells of the germ-disc are columnar in type and are marked off from the entoderm by a basement membrane. By the third week they form three or four interlocking rows of cells (fig. 78). The cells of the amnion are flatter and more elongated and form only a single stratum, which is covered with a layer of primary mesoderm. The entodermal cells of the embryonic shield are flattened, but those lining the rest of the yolk-sac vary in shape and patches of cubical or low columnar cells are found, especially on the caudal wall. Except in certain situations, to be noted later, the entoderm never forms more than a single layer of cells.

One inconstant feature of the embryo at this stage deserves mention. The presence of a short stalk connecting the amnion to the trophoblast has already been noticed. This stalk consists of primary mesoderm and may contain a duct, termed the *amniotic duct*, which communicates with the amniotic cavity, but ends blindly near the trophoblast.

In the reptilia, and in many mammals, the amnion arises as a fold around the periphery of the embryonic shield and soon closes in to form a vesicle. The amniotic duct of the human embryo has been interpreted as the homologue of the point of closure of this fold, but it has been suggested that its presence depends on the chance occurrence of a trophoblastic lacuna which breaks through into the amniotic cavity.

Concomitant with the changes which transform the ovum into a morula, the ovum is gradually carried along the uterine tube by the action of the cilia of its lining epithelium. The passage along the tube probably covers a period of about three days. The morula is transformed into a blastocyst which remains free in the uterine cavity for a further three days before implantation. During this interval the uterine mucosa is preparing for the reception of the fertilised ovum. The disappearance of the zone pellucida, after the formation of the blastocyst, allows the trophoblast cells to come into direct contact with the uterine mucosa.

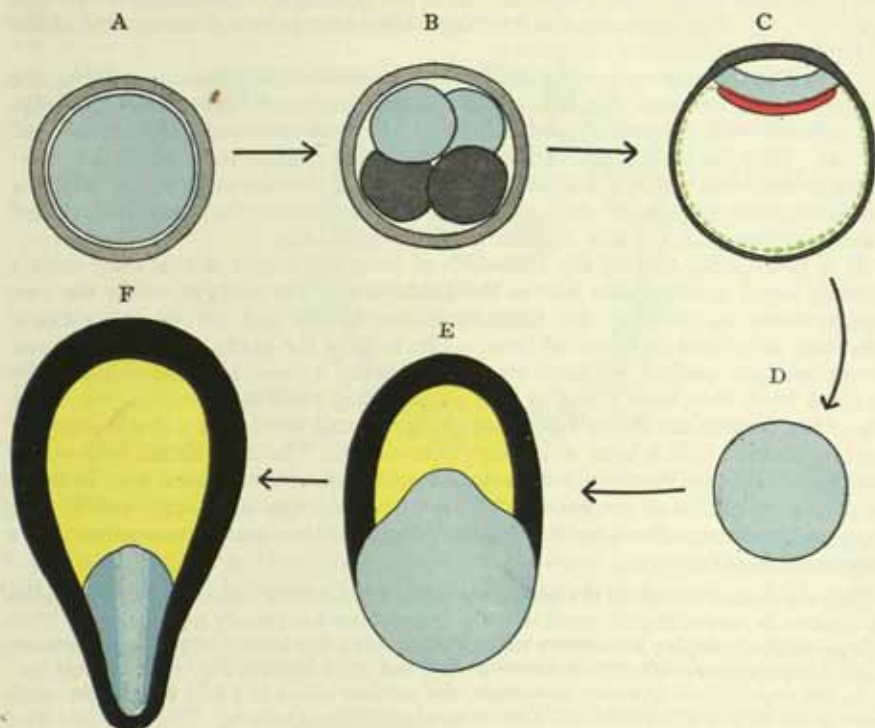
Applied Anatomy.—Sometimes the fertilised ovum is arrested in the uterine tube, and undergoes development there, giving rise to a *tubal pregnancy*; or it may fall into the abdominal cavity and produce an *abdominal pregnancy*; occasionally a fertilised ovum or embryo is found developing within the ovary itself. This is termed an *ovarian pregnancy*, and it is generally stated that in this case the ovum has remained within the follicle after its rupture and been fertilised *in situ*. It is probable, however, that in most cases, at any rate, the ovum has been fertilised in the abdominal cavity and has later embedded itself in the ovary.

The differentiation of the embryonic area.—The embryonic area shows no distinguishing features in its earliest stages. At first nearly circular, its outline rapidly alters and becomes oval, indicating the long axis of the body. This growth in length is associated with a further differentiation of the cells in the germ-disc, resulting in the formation of ectoderm and neurectoderm cells. The former dispose themselves around the anterior and lateral margins of the embryonic shield, and the latter—at first indistinguishable in appearance from the ectoderm cells proper—form a crescentic shaped *medullary plate* within the ectoderm-covered area (fig.

^{*} Some investigators (C. H. Heuser and G. L. Streeter, *Contr. Embryol. Carnegie Instn.*, 29, 1941) maintain that the definitive yolk-sac is a new formation on the under surface of the germ disc.

75, E.). The remaining pluripotent cells are therefore now restricted to the caudal half of the embryonic shield, where they occupy a broad central strip. The oval

FIG. 75.—A diagram to illustrate Streeter's conception of the origin of the primitive streak. (After Streeter, *Contr. Embryol. Carneg. Instn.*, 29, 1941.)



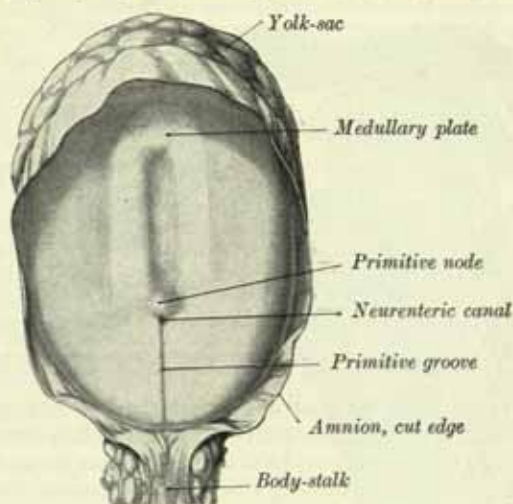
A. The totipotent ovum within the zona pellucida. B. The four-celled stage. Two of the cells retain a high degree of potency (blue). C. Section through the early blastocyst. The cells of the germ-disc remain pluripotent (blue). The other cells have become differentiated into trophoblast, endoderm and primary mesenchyme. D. The embryonic area of C, dorsal view. E. Dorsal surface of the embryonic area at a later stage. The skin-ectoderm (black) and the neurenteric (yellow) have been differentiated from the pluripotent cells of the germ-disc (blue), which now lie in the caudal half of the area. F. The same view at a still later stage. The skin-ectoderm (black) and the neurenteric (yellow) areas have increased in size and the residual pluripotent cells (blue) constitute the primitive streak, which shows a median primitive groove.

embryonic area becomes pear-shaped, and in the median plane of its narrower portion there appears a localised opacity, which soon elongates to form a linear opacity, termed the *primitive streak* (fig. 75). The cells of the primitive streak represent the remaining cells of the germ-disc which still retain their pluripotency and continue to differentiate rapidly (see also p. 79). It must be remembered that in the early stages of development the living tissues are translucent, but any localised thickening due to cellular proliferation naturally interferes with the translucency and causes a localised opacity. The linear opacity of the primitive streak indicates that rapid growth is occurring throughout its site. At its headward end a further area of exceptionally active growth forms a knob-like thickening which is termed the *primitive node* (fig. 76). Here the ectoderm is fused with the endoderm.

From the primitive node a rod-like process of cells grows headwards in the median plane and separates the medullary plate from the subjacent roof of the yolk-sac (fig. 84). This is termed the *head process*, and it is the forerunner of the skeletal axis of the body. The solid rod of cells becomes canaliculised (fig. 77) and at its caudal end the canal breaks through on to the ectodermal surface at the posterior end of the primitive node. The entodermal cells lying ventral to the head process disappear, and the head process then becomes, for the time being, a constituent part of the roof of the yolk-sac in the median plane. The cells forming the floor of the canal of the head process break down so that the canal communicates freely with the yolk-sac and, at its caudal end, a communication is established between the yolk-sac and the amniotic cavity. This connexion, which pierces the embryonic area at the primitive node, is termed the *neurenteric canal*. At this stage a transverse section across the embryonic area cranial to the primitive node shows that,

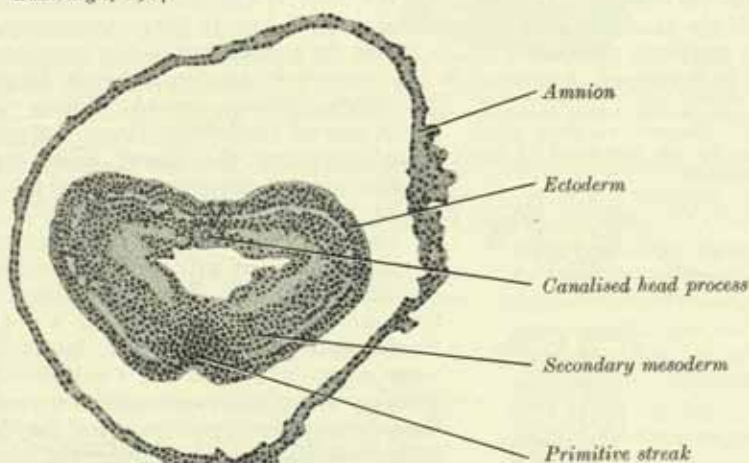
in the median plane, the roof of the yolk-sac is formed by the cells of the head process (fig. 78), and this intercalation, which forms the *chordal* or *notochordal plate*, extends

FIG. 76.—A human embryo, 1.16 mm. long. The amnio-embryonic vesicle has been laid open widely, most of the amnion having been removed. The embryonic area is exposed in almost its whole extent and shows an early stage of differentiation. Estimated age, 19 days. (W. C. George, *Contrib. Embryol.*, 30, 1942.)



forwards to the region which will subsequently form the pharynx. Later, these cells of the head process become excalated out from the entoderm and form the *notochord*,

FIG. 77.—Transverse section of the tail-fold of a human embryo, about 19 days old (Embryo: Bryce-McIntyre). From Bryce's "Observations on the Early Development of the Human Embryo," *Transactions of the Royal Society of Edinburgh*, 1924.

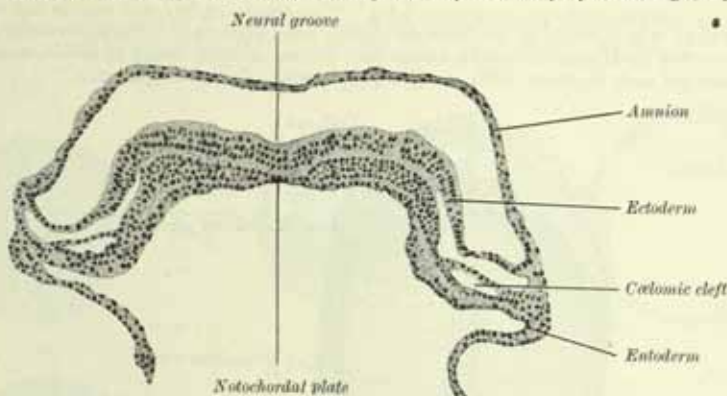


The canaliculised head-process lies in the roof of the hind-gut. The primitive streak and groove lie on the ventral aspect of the tail-fold. Observe that the secondary mesoderm is continuous ventrally with the primitive streak, and that the tail-fold is lying within the amniotic cavity.

the roof of the yolk-sac being repaired by the fusion of the adjoining entodermal cells. Subsequently the cells of the notochord develop around them a homogeneous sheath, and the continued proliferation of the cells within the sheath results in the formation of a solid but flexible rod, which becomes surrounded by mesenchyme to form the primitive or blastemal vertebral column (p. 103).

During the earlier part of this period another important change occurs which affects nearly the whole of the embryonic area. From the sides of the primitive streak there is an intensely active cell growth. These cells spread laterally and forwards until they extend over the whole embryonic area *with the exception of the*

FIG. 78.—Transverse section of a human embryo, about 19 days old (Embryo : Bryce-McIntyre). From Bryce's "Observations on the Early Development of the Human Embryo," *Transactions of the Royal Society of Edinburgh*, 1924.



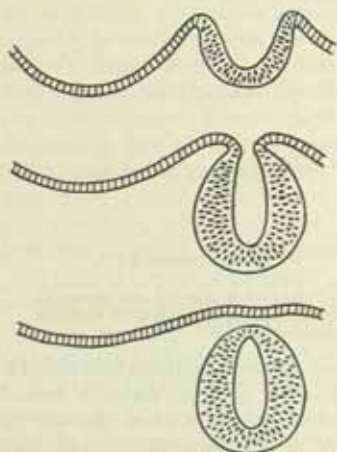
The canal of the head-process has broken into the yolk-sac at this level and the notochordal plate is incorporated in the roof of the gut. Observe that coelomic clefts have appeared in the lateral plates of the mesoderm, and that they do not communicate with the extra-embryonic coelom. The neural groove is shallow and the amnion is restricted to the dorsal and lateral aspects of the embryo.

median plane. They insinuate themselves between the ectoderm and the underlying entoderm and constitute a third constituent layer, which is termed the *secondary mesoderm* (fig. 77). At the extreme cephalic end of the area the secondary mesoderm does cross the median plane, constituting what has been termed the '*pericardial bar*' (fig. 84).

The primitive streak is the principal but not the only source of secondary mesoderm. Cephalic to the headward end of the head process, the entoderm in the roof of the yolk-sac becomes thickened and gives rise to a plate of large vesiculous cells which has been termed the *prochordal plate*. This plate contributes secondary mesoderm to the head region (p. 79). It must be stated, however, that there is much experimental evidence in favour of the view that the mesenchyme of the head and of the visceral arches (p. 108) is derived from cells which migrate from the deep aspect of the headward end of the neural crest, at least in lower vertebrates.*

The *medullary plate*, from which by far the greater part of the central nervous system is developed, lengthens as the embryonic area increases in length and its margins become raised. These margins, which extend caudally as far as the primitive node, constitute the *neural folds*, and the median groove between them is the *neural groove*.

FIG. 79.—Diagram to show three stages in the formation of the neural tube.



Note that when the neural groove closes, skin-ectoderm fuses with skin-ectoderm and neur ectoderm with neur ectoderm.

* S. Hörstadius (in *The Neural Crest*, Oxford Univ. Press, 1950) summarises the literature on this subject.

ally occurs, like fuses with like, i.e. skin ectoderm with skin ectoderm, and neural tissue with neural tissue. The process is effected first in the region of the hind-brain (fig. 80) in the latter part of the third week, and extends both headwards and tailwards, until only a small opening is left at each end. These openings are termed the anterior and posterior *neuropores*; the former closes in the middle, and the latter towards the end, of the fourth week. The cells which lie in the line of fusion of the dorsal edges of the neural groove constitute the *neural crest* (fig. 136), the history of which will be considered in a subsequent section (p. 128).

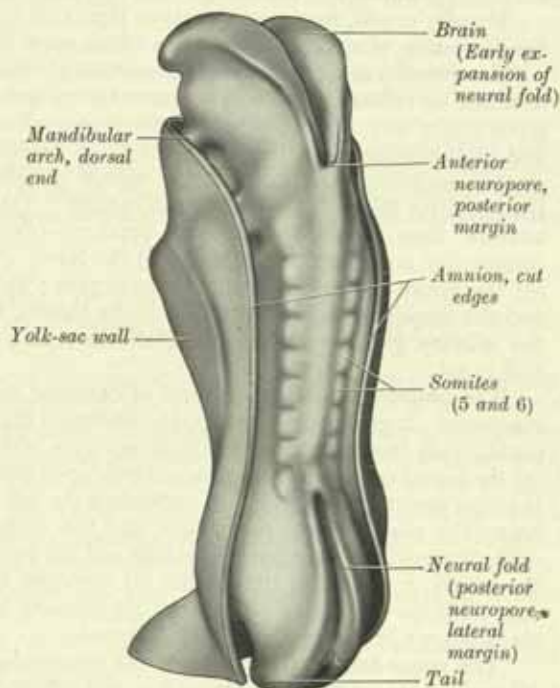
From the time when they become differentiated the walls of the neural groove are bathed by the fluid in the amniotic cavity (*liquor amnii*) and presumably are dependent on it for their nourishment so long as the neuropores remain open. It is a significant fact that closure of the neuropores coincides with the establishment of a blood-vascular circulation for the neural tube.

The fusion of the dorsal lips of the neural groove in the region of the brain results in the formation of the three *primary cerebral vesicles*. The walls of these vesicles become thickened and develop into the nervous tissue and neuroglia of the brain, and the cavities are modified to form the ventricles of the brain. The

remainder of the tube forms the spinal medulla, its cavity persisting as the central canal.

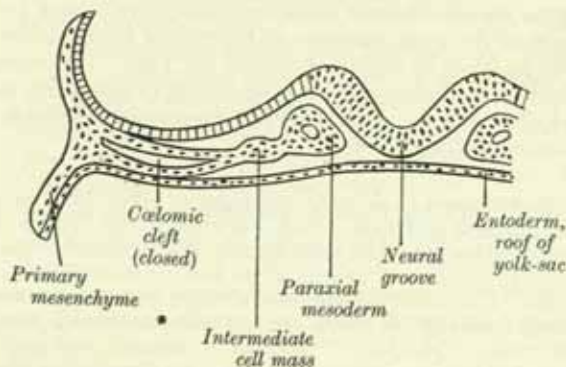
Throughout the region of the notochord the secondary mesoderm arranges itself in (1) a thickened medial portion which lies immediately lateral to the neural

FIG. 80.—Model of a human embryo, 2.1 mm. long, with nine somites. Viewed from the left lateral and dorsal aspects. (From a model by Eternod.)



Note. Nearly all the yolk-sac has been cut away, and at the caudal end a portion of the amnion has been excised to show the tail region.

FIG. 81.—Diagram to show the differentiation of the secondary mesoderm.



groove and is termed the *paraxial mesoderm* (fig. 81), (2) a narrower portion, termed the *intermediate cell mass*, situated to its lateral side and directly continuous with it, and (3) a flattened lateral portion, continuous medially with (2), which extends over the surface of the embryonic area to its periphery, where it becomes continuous with the primary mesenchyme on the outer surfaces of the amnion and the yolk-sac. This portion is termed the *lateral plate*.

The appearance of the secondary or intra-embryonic mesoderm completes the first stage of differentiation in the embryonic area. The embryo now consists of an outer, protective layer, the ectoderm, an inner nutritive layer, the entoderm, and an intermediate layer, the

mesoderm, which is available primarily as a muscle-forming layer. It is clear from their history and their early differentiation that these layers are of considerable significance, but too much stress must not be laid on their independence from one another. In other words, the differentiation reached at this stage has not gone so far as to leave the constituent cells of the three layers with potencies so limited that complete divergence is assured for the future. The potencies of the individual cell layers are reduced from the pluripotent condition found at an earlier period, but not to such an extent that the potencies of the cells of one layer are entirely different from those of the two remaining layers.

Broadly stated, however, the three layers in the human embryo contribute to the formation of systems and organs which show distinct functional differences.

The **ectoderm** consists of columnar cells, which, however, become somewhat flattened or cubical, especially towards the periphery of the embryonic area. It gives origin to: (1) the skin and the lining cells of the glands which open on it, and its appendages, the hair and nails; (2) practically the whole of the nervous system, including the cranial and spinal ganglia, the sympathetic ganglia and the posterior lobe of the hypophysis cerebri; (3) the chromaffin organs; (4) the anterior lobe of the hypophysis cerebri; (5) the epithelium of the cornea, conjunctiva and lacrimal glands; (6) the lens; (7) the plain muscle of the iris; (8) the neuro-epithelium of the sense-organs; (9) the epithelium lining the nose and the paranasal sinuses, the roof of the mouth, the gums, and the cheeks; (10) the salivary glands and the enamel of the teeth; and (11) the lower part of the anal canal.

The **entoderm** consists at first of flattened cells, which subsequently become columnar. It gives origin to: (1) the epithelial lining of the whole of the alimentary canal, with the exception of those portions already ascribed to the ectoderm; (2) the lining cells of all the glands which open into the alimentary canal, including the liver and the pancreas, but excluding the salivary glands; (3) the epithelium lining the pharyngo-tympanic tube and the tympanic cavity; (4) the epithelium of the thyroid and parathyroid glands and the thymus; (5) the lining epithelium of the larynx, trachea and the smaller air passages, including the alveoli and the air-cacs; (6) the epithelium of most of the urinary bladder and the adjoining part of the urethra; (7) the epithelium of the prostate.

The **mesoderm** gives origin to the remaining organs and tissues of the body. These include: (1) all the connective and sclerous tissues; (2) the teeth, with the exception of the enamel; (3) the whole musculature of the body, both striated and unstriated, with the exception of the musculature of the iris; (4) the blood and the blood-vascular and lymphatic systems; (5) the urogenital system, with the exception of most of the urinary bladder, prostate and urethra; (6) the cortex of the suprarenal glands and the mesothelial linings of the pericardial, pleural and peritoneal cavities.

It should be observed that the cells of the mesoderm are very soon differentiated into those which subsequently retain their close-packed cellular character (*mesoderm proper*) and those which form a loose tissue with a fluid matrix (*mesenchyme*). Thus the muscles and urogenital organs are mesodermal while the connective tissues are mesenchymatous, and on account of the fluid character of the matrix their cellular elements are able to alter their position by active migration (p. 103). The term *mesothelium* is sometimes applied to epithelial cells of mesodermal origin, such as the secretory epithelium of the kidney and the cortical cells of the suprarenal glands, as well as to the lining of the serous cavities (p. 7).

A detailed consideration of the processes of early development in other vertebrata and lower chordata is outside the scope of this book. Such a study however can be of value in the interpretation and understanding of the early history of the human ovum. The human egg resembles that of amphioxus in respect of its low content of deuto-plasm and is termed *microlecithal*. Consequently the ova of these two species are similar in their manner of cleavage whereby the whole egg is subdivided into a mass of cells of approximately equal size. The type of cleavage is termed *holoblastic*. Subsequent development however shows marked differences. In *Amphioxus* the whole ovum gives rise to the embryo, whereas in the human only a small proportion of the cells to which it gives origin actually contribute to the formation of the embryo. In this the human ovum resembles the condition in reptiles and birds where the egg is heavily yolked or *macrolecithal* and only a small portion of it is involved in cleavage

and subsequent formation of the embryo. This partial cleavage is termed *meroblastic*. This indicates that the holoblastic character of the human ovum is secondary and has evolved from an ancestral meroblastic condition. For a similar reason the cavity of the human blastocyst cannot be homologised with the blastocoele of the amphioxus ovum and the latter term is best avoided in connexion with human development.

The process of entoderm formation in the human ovum, and indeed in reptiles and birds, has been so modified and abbreviated as to render a comparison with the process in amphioxus difficult and uncertain.

From a study of comparative embryology and in particular of amphibian development it seems fairly clear that the primitive node, which is concerned with the formation of the notochord, is the homologue of the dorsal lip of the blastopore of lower vertebrates and that the neurenteric canal is a persisting remnant of the blastopore. Following this homology further it would appear that the primitive streak represents the fused lateral lips of the blastopore and is responsible for the origin of the mesoderm (*prostomial mesoderm*) which arises in lower vertebrates by continued proliferation at the lateral lips of the blastopore. The earlier mesoderm (*gastral mesoderm*) in these forms is invaginated during gastrulation and subsequently constricted from the roof of the archenteron. In mammals and other higher vertebrates the intra-embryonic mesoderm, although mainly derived from the primitive streak, receives a contribution from the prochordal plates which initially lie adjacent to the cranial end of the head process.

THE SEGMENTATION OF THE MESODERM AND THE FORMATION OF THE INTRA-EMBRYONIC CÆLOM

In the embryos of all vertebrate animals the intra-embryonic mesoderm becomes incompletely subdivided by a longitudinal groove into a *paraxial portion* and a *lateral plate*, on each side of the median plane. The mesoderm in the floor of the groove which connects these two portions is termed the *intermediate cell mass*, or *nephrogenic cord* (fig. 81). Soon after the appearance of this longitudinal groove the paraxial mesoderm becomes subdivided into a series of cubical blocks by a series of transverse grooves. This process is termed the *segmentation of the mesoderm*, and the blocks of paraxial mesoderm so formed are known as *mesodermic somites*, *primitive segments* or *metameres*. Commencing at the end of the third or the beginning of the fourth week in the region of the hind brain (fig. 80), the process extends in a caudal direction, additional somites being laid down as the embryo grows in length, until some thirty-five or more pairs are present (fig. 130). In the human embryo it is only the paraxial mesoderm which is actually segmented, but in view of the obviously segmental arrangement of the nerves of the spinal medulla and their distribution, it is reasonable to suppose that the segmentation of the other structures is only obscured. The whole process may be regarded as evidence that the invertebrate ancestor of all vertebrate animals showed clear signs of its segmental origin.

Each mesodermic somite at first contains a central cavity termed the *myocoele*. The cells of the ventrimedial portion of the somite constitute the *sclerotome*. They migrate medially and give rise to the *scleratogenous tissue* from which the axial skeleton is ultimately derived (p. 103). The cells of the dorsilateral portion of the somite constitute the *dermomyotome*. Spindle shaped cells proliferate from its margins to form the *muscle-plate* or *myotome* (p. 123), the remaining epithelially arranged cells constitute the *skin-plate* or *dermatome* (fig. 83).

In the initial stages of somite formation a cavity appears in the pericardial bar (p. 154) and this cavity is the first indication of the *intra-embryonic cælo*m. As the segmentation of the mesoderm proceeds a number of clefts are formed on each side in the lateral plate, which thus becomes divided into a *somatic* and a *splanchnic layer* (fig. 81). The somatic layer, with its covering of ectoderm, constitutes the *somatopleure*, and the splanchnic layer, with the underlying entoderm, constitutes the

FIG. 82.—Cross-section through the body of a human embryo at the end of the fourth week, to show the arrangement of the mesoderm. Diagrammatic.

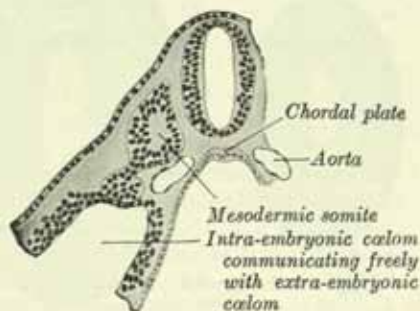
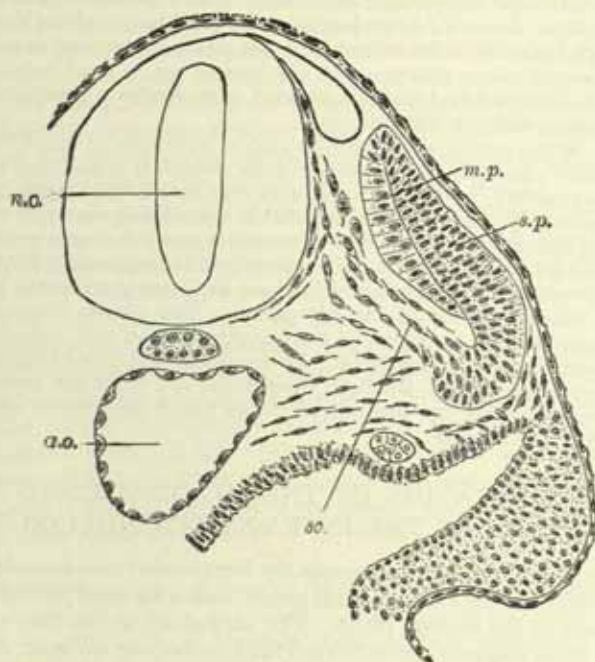
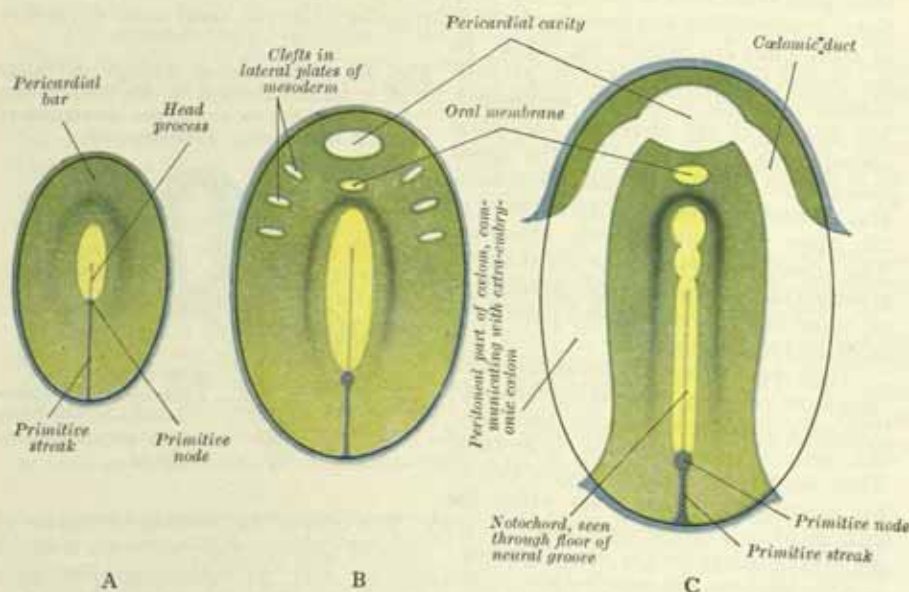


FIG. 83.—A transverse section of a human embryo of the fourth week, to show the differentiation of the primitive segment. (Kollmann.)



a.c., aorta; *m.p.*, muscle-plate; *s.p.*, skin-plate; *n.c.*, neural cana *sc.*, sclerotome.

FIG. 84.—Diagrams to illustrate the formation of the intra-embryonic coelom. The embryonic area is viewed from the dorsal aspect. In B and C the early stages of the head and tail folds are not shown.



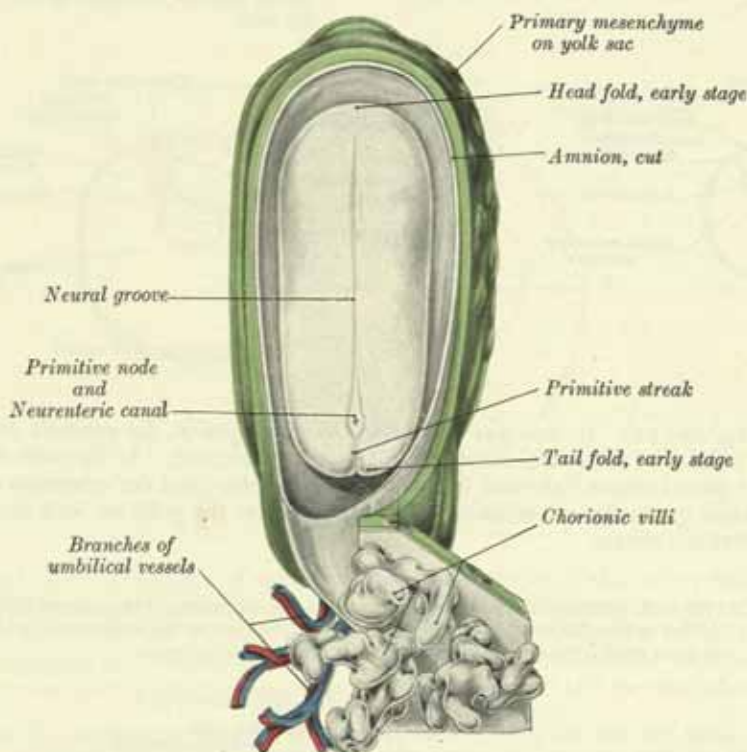
In A the secondary mesoderm, shown in green, becomes continuous with the primary mesoderm shown in blue, around the periphery of the embryonic area. At the headward end the secondary mesoderm extends from side to side across the median plane, forming the pericardial bar, but the region of the developing neural groove, shown in yellow, is devoid of mesoderm.

In B the pericardial cavity, shown uncoloured, has appeared in the pericardial bar, and a series of clefts, also shown uncoloured, has appeared in the lateral plate mesoderm on each side. The oral membrane, which is devoid of secondary mesoderm is shown in yellow.

In C the clefts have extended and run into one another and into the pericardial cavity, forming a colomic duct on each side. In the caudal part of the area additional clefts have formed, coalesced and broken through into the pleuro-pericardial canals and into the extra-embryonic coelom.

splanchnopleure. The lateral extremities of the cavity in the pericardial bar extend caudally so as to link up with the clefts and as a result the intra-embryonic cœlom is laid down as an inverted U-shaped tube, from which the pericardial, pleural and peritoneal cavities are subsequently developed. Around the periphery of the

FIG. 85.—Dorsal view of a human embryo, 1.3 mm. long. (From a model by Eternod.)



embryonic area the somatopleure and the splanchnopleure are continuous, at first, both with each other and with the primary mesenchyme (fig. 81). Soon, however, the cavity extends beyond the embryonic area, the continuity between the somatopleure and the splanchnopleure is broken, and the intra-embryonic cœlom is thrown into free communication with the extra-embryonic cœlom (fig. 84, C). This process does not affect the pericardial area or the regions immediately adjoining it on either side; the latter are the *cœlomic ducts* (fig. 84, C).

The early formation of the cœlom and its free communication with the extra-embryonic cœlom allows the fluid which fills the latter to gain access to the interior of the embryo. It therefore may act as a source of nutriment during the period which has still to elapse before the establishment of a blood-vascular circulation. The walls of the cœlom are formed of undifferentiated mesodermal cells (mesoblasts), which rapidly proliferate (fig. 82). From the mesoblast of the somatopleure, or perhaps of the dermatome, the corium and the subcutaneous tissue are formed, while those of the splanchnopleure become differentiated into the muscular walls of the heart and gastro-intestinal tract. It is not until a later stage that the mesoblasts which line the cœlom become differentiated into the characteristic mesothelium of the pericardium, pleura and peritoneum.

THE FORMATION OF THE EMBRYO

The formation of the head and tail folds.—Hitherto we have been dealing with a disc-like embryonic area, but at the end of the third week of its development the embryo begins to assume its definitive shape. The immediate cause of this alteration is the difference in the rate at which adjoining areas are growing. The

rate of growth in the periphery fails to keep pace with the rate of growth within the embryonic area, and, as the embryo is increasing more rapidly in its long axis especially at its cephalic end where the walls of the neural groove are expanding to form the fore-brain, both extremities tend to project beyond the limits of the area

FIG. 86.—A diagram showing an early stage in the development of the human ovum.

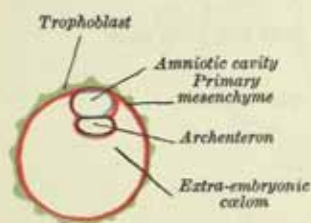
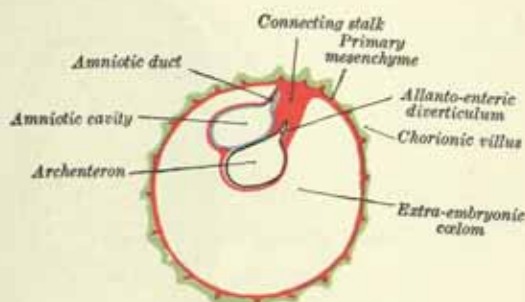
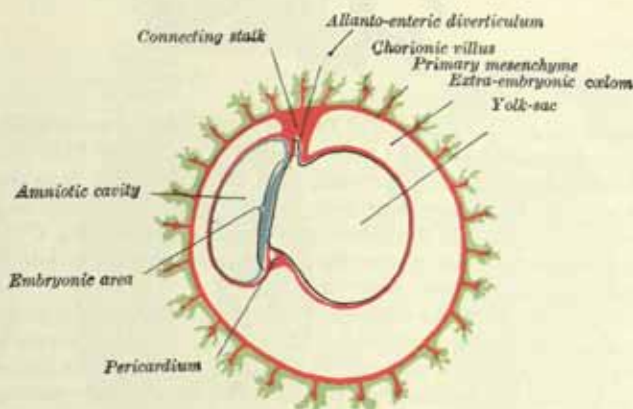


FIG. 87.—A diagram illustrating the early formation of the allanto-enteric diverticulum and the definition of the connecting stalk.



(figs. 89, and 92). In this way a *head-fold* is developed at the cephalic extremity and a *tail-fold* at the caudal extremity of the embryonic area. At the same time and for the same reasons right and left *lateral folds* develop, and the extension of these four folds gradually constricts off the embryo from the yolk sac and gives it its characteristic shape.

FIG. 88.—A diagram showing a later stage of the development of the human embryo. Observe that the heart occupies the most anterior part of the embryonic area and is separated from the prosencephalon by the oral membrane.



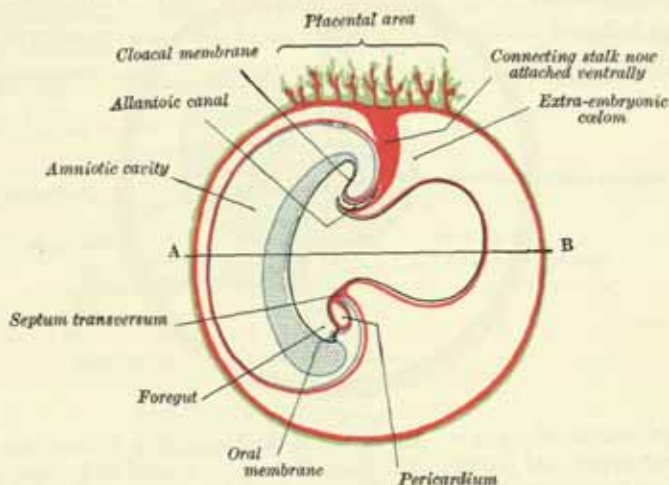
As a result of the formation of the head-fold, the prosencephalon, which was hitherto separated from the cephalic extremity of the embryonic area by the oral membrane (p. 76) and the pericardium, comes to lie at the cephalic extremity of the embryo (figs. 89, 91). This alteration in position of the fore-brain is accompanied by a corresponding alteration in the relative positions of the oral membrane and the pericardium (figs. 167 and 169). The former now lies on the ventral surface and is situated at the bottom of a depression, which constitutes the primitive mouth or *stomodæum*. On its cephalic side the stomodæum is bounded by the projecting fore-brain and on its caudal side by the pericardium. The latter has not only altered its position relative to the cephalic extremity of the embryo but has also undergone a reversal of its surfaces, as will be pointed out later.

In addition to these alterations the head-fold results in the inclusion within it of a portion of the yolk-sac. This included portion is termed the *fore-gut* and it is placed

between the oral membrane and the pericardium, on its ventral aspect, and the hind-brain, dorsally (fig. 169). It communicates at its caudal end with the midgut through an opening often termed the *anterior intestinal portal*.

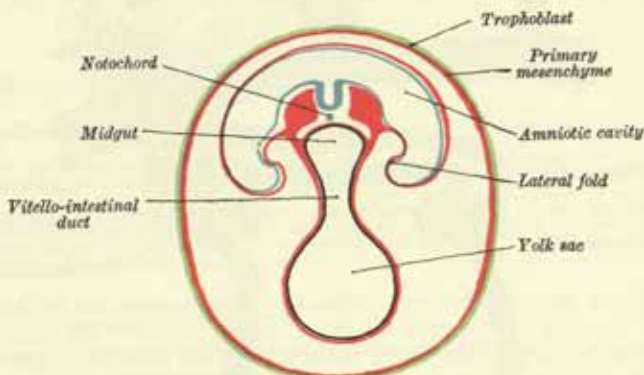
The ventral bend of the head-fold produces a well-marked flexure in the brain at the site of the mesencephalon, termed the *cephalic flexure*.

FIG. 89. —A diagram showing the formation of the head- and tail-folds, the expansion of the amnion, and the delimitation of the umbilicus.



Prior to the formation of the tail-fold the caudal end of the embryonic area is anchored to the trophoblast by the connecting stalk, which is covered on one aspect by the mesothelium of the amnion (fig. 88). The formation of the tail-fold carries the connecting stalk round on to the ventral aspect of the embryo, so that it now assumes the permanent position of the umbilical cord. It will be remembered that

FIG. 90. —A diagram showing a transverse section along the line AB in fig. 89. Observe that the intra-embryonic coelom communicates freely with the extra-embryonic coelom.

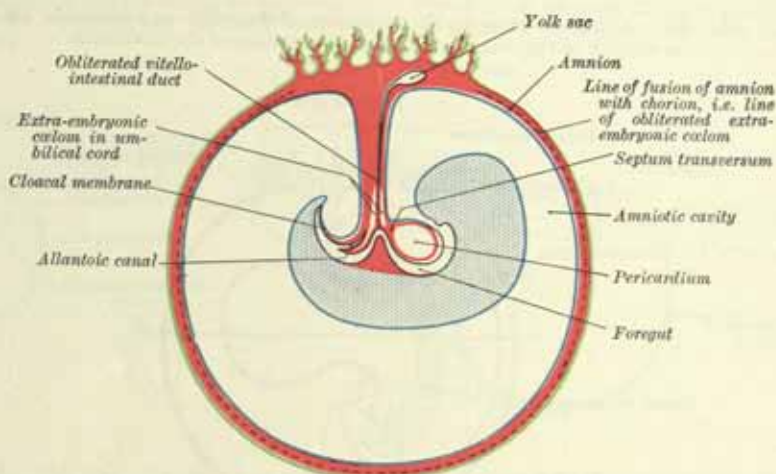


the stalk was connected to the embryo at the caudal end of the primitive streak, and, in consequence of the formation of the tail-fold, the primitive streak like the connecting stalk extends round towards the ventral aspect of the embryo to the region which later lies immediately behind the anal orifice. Some authorities, however, hold the view that the primitive streak is continued into the rudimentary tail and does not appear in the perineum or on the ventral surface of the embryo.

Just as a portion of the yolk-sac is included within the head-fold to form the fore-gut, so a corresponding portion is included within the tail-fold to form the *hind-gut*. But the similarity between these two included portions goes further. A portion of the entoderm in the floor or ventral wall of the fore-gut comes into direct contact

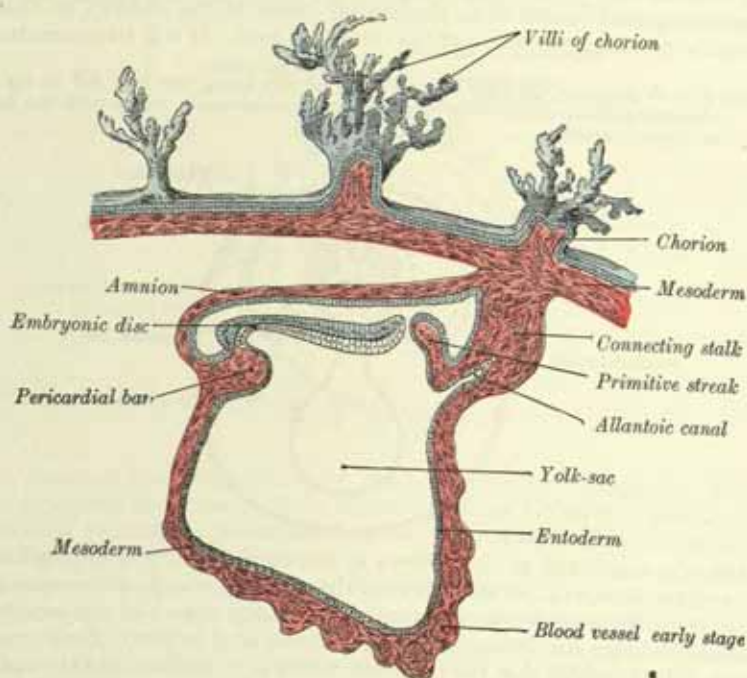
with the ectoderm over an area which is termed the oral or buccopharyngeal membrane (p. 76). This membrane soon disappears and the communication of the gut with the exterior through the mouth is thus established. In the region of the hind-

FIG. 91.—A diagram illustrating a later stage in the development of the umbilical cord.



gut a similar relationship exists. Even before the tail-fold is defined, the ectoderm and entoderm come into contact with each other at the caudal end of the embryonic area, forming the *cloacal membrane* (fig. 93, A). As will be described later, this

FIG. 92.—A sagittal section through the embryo which is represented in fig. 85. The cloacal membrane is not shown. (After Graf Spee.)

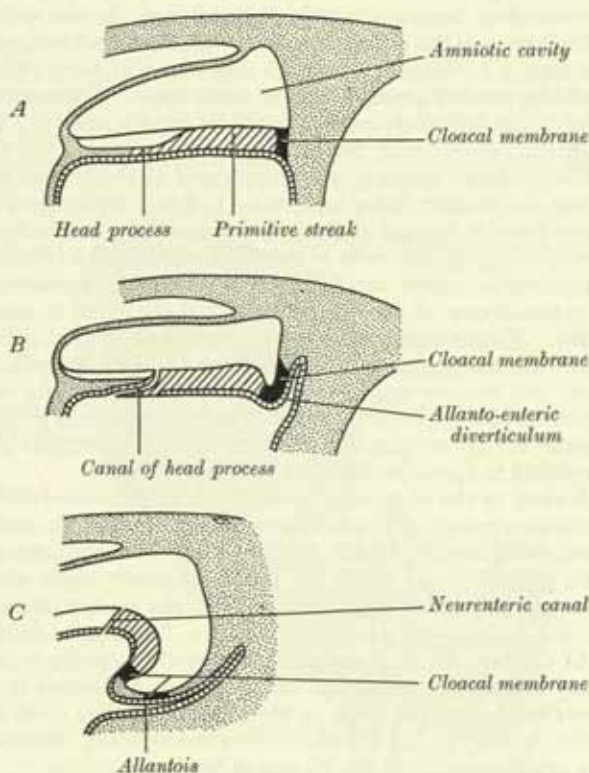


membrane subsequently breaks down in two places to form the urogenital and anal orifices.

Prior to the formation of the tail-fold a diverticulum arises from the dorsio-caudal portion of the yolk-sac and grows into the mesenchyme of the connecting stalk

(fig. 87). This outgrowth constitutes the *allanto-enteric diverticulum* (fig. 93, *B*). As the tail-fold becomes defined the proximal part of the diverticulum becomes incorporated in the hind-gut, and its distal portion persists as the allantoic canal or *allantois* (p. 87), which then communicates directly with the ventral surface of the hind-gut. The portion of the hind-gut which lies caudal to this communication forms the *entodermal cloaca* (p. 193). As the tail-fold is formed, the cloacal membrane comes to lie in the ventral wall of the hind-gut but it extends also on to the adjoining dorsal aspect of the connecting stalk, where it is associated with the allantoic portion of the allanto-enteric diverticulum (fig. 93, *C*). Even before the latter is incorporated in the hind-gut, the cloacal membrane becomes interrupted

FIG. 93.—Three stages in the development of the cloacal membrane.
(J. Florian.)



A. Prior to the formation of the tail-fold and the allanto-enteric diverticulum.

B. The tail-fold is indicated and the allanto-enteric diverticulum has formed. The cloacal membrane now extends in relation with the enteric part of the diverticulum on to the dorsal aspect of the body-stalk.

C. The tail-fold is clearly defined. Mesoderm has become interposed between the ectoderm and endoderm over the proximal part of the allanto-enteric diverticulum and the cloacal membrane is thus broken up into two parts, of which only the proximal one persists.

The mesoderm is shown stippled.

and shortened by the interposition of mesenchyme between the entoderm of the diverticulum and the covering epithelium of the body-stalk * (fig. 93, *C*).

Between the head- and the tail-folds the embryo becomes constricted off by right and left lateral folds. The intervening dorsal portion of the yolk-sac, which these folds threaten to cut off, and later succeed in separating from the remainder of the vesicle, constitutes the *mid-gut*. At first the mid-gut communicates freely on its ventral surface with the rest of the yolk-sac, but the continued growth of the folds results in a narrowing of the connexion, which becomes drawn out as the *vitello-intestinal duct* (figs. 90 and 91). The remainder of the yolk-sac remains extra-embryonic and is often termed the *umbilical vesicle*. The subsequent history of the duct and the vesicle will be dealt with later (pp. 188, 195).

The nutrition of the embryo.—In the early stages of development the cells of the ovum derive their nourishment from the store laid up within the cell body of

* J. Florian, *J. Anat. Lond.*, 64, 1930.

the primary oöcyte. It is probable that this nourishment is at first maintained in a highly concentrated form and is subsequently liberated in a more dilute form, readily available for absorption, in the cavity of the blastocyst, and also in the primary yolk-sac and later in the definitive yolk-sac (p. 72). In addition, it has been suggested that the blastocyst derives nourishment from the uterine glands and, during the process of embedding, from the portion of the uterine wall which has been destroyed. There follows a period of about two weeks during which the embryonic disc is dependent on the nutriment it can obtain from the fluids which fill the cavities of the amnion, the cœlom and the yolk-sac. These fluids probably contain material absorbed by the trophoblast from the uterine tissues and the maternal blood, modified, perhaps, as they diffuse through the amnion and the wall of the yolk-sac. However, at an early stage in development these sources of supply are cut off. The neural groove is converted into a blind tube by the closure of the neuropores, the exocœlom becomes greatly reduced (figs. 89 and 91) and is later shut off from the cœlom, and the obliteration of the vitelline duct separates the yolk-sac from the gut-tract. It therefore becomes essential that some other source of food-supply should be rendered available at an early stage. The maternal circulation is selected, but it can only function as a source of supply when it is brought into close, though indirect, contact with the embryonic circulation. On this account, the formation of angioblastic tissue is very precocious in the human embryo.

The work of van der Stricht, Sabin and others makes it highly probable that the earliest angioblastic tissue is formed in the deepest part of the mesenchyme covering the entodermal vesicle or yolk-sac, early in the third week. About the same time, or slightly later, angioblastic tissue can be recognised in the connecting stalk and in the primary mesenchyme of the chorion, and a little later it appears also in the embryonic area. Tissue spaces form in the angioblast and the cells which line these spaces take on the characters of typical, flattened endothelial cells, and adjoining spaces run into one another and form a capillary plexus. While the spaces are in process of formation small, localised groups of mesodermal cells project into their interior and become cut off to form blood islets. The constituent cells of these islets become modified to form the blood corpuscles (p. 153).

The vessels formed in the chorion soon establish an intimate relationship with the maternal circulation (p. 90). The vessels which develop in the embryonic area form two longitudinal channels, which, at their headward ends, project into the dorsal wall of the pericardium. They are the rudimentary right and left dorsal aortæ, and at their cephalic ends, after curving ventrally on the lateral wall of the pharynx to reach the cephalic end of the pericardium, they fuse to form a primitive tubular heart. At the caudal end of the embryo they traverse the connecting stalk as the rudimentary umbilical arteries and break up into capillaries in the chorion. The venules from the chorion converge on the stalk where they form the right and left umbilical veins, which run headwards in the somatopleure, close to the margin of the embryonic area, to reach the caudal end of the heart.

It will be remembered that the pericardial cavity never communicates directly with the extra-embryonic cœlom, and at its cephalic limit the somatopleure and splanchnopleure become continuous (fig. 167). With the formation of the head-fold the surfaces of the pericardium are reversed, and the original cephalic limit comes to lie in intimate relation with the wall of the fore-gut at the ventral border of the anterior intestinal portal (fig. 169). As the floor (caudal limit) of the pericardium deepens ventrally, the mesenchyme between it and the gut forms a sheet, which is termed the *septum transversum*. Prior to reversal this mesoderm forms a U-shaped mass intervening between the pericardium and the extra-embryonic cœlom. The septum transversum later plays an important part in the development of the diaphragm. At this stage it is bounded on its headward surface by the pericardium and on its caudal surface by the fore-gut; on its dorsal surface it is limited by the cœlomic ducts, which connect the pericardium with the peritoneal cavity and on its lateral surface by the opening of the peritoneal cavity into the extra-embryonic cœlom which bounds it below. The umbilical and body-wall veins, which run in the somatopleure, and the vitelline veins, which run in the splanchnopleure, meet one another in the septum transversum and so gain the venous end of the heart.

In this way there is established the circulation, through the vessels and tissues of the embryo, of blood which has derived oxygen and nutriment from the maternal circulation.

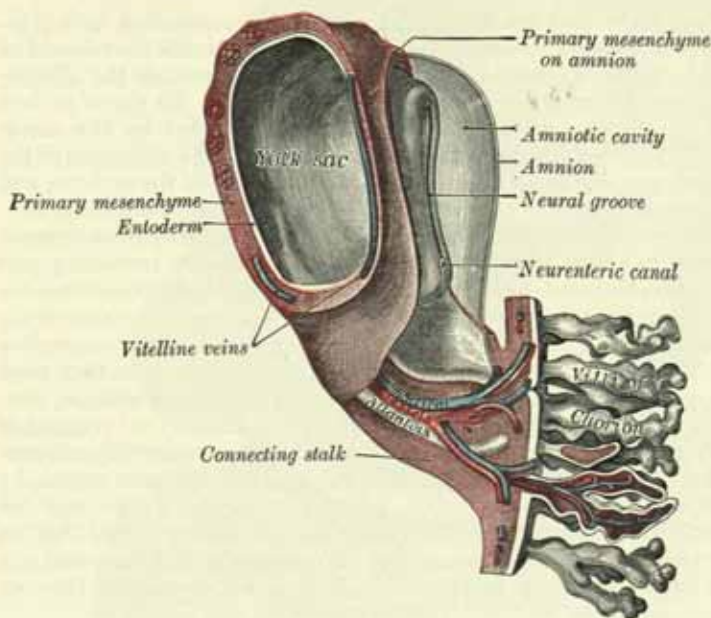
THE FŒTAL MEMBRANES AND THE PLACENTA

The allantois (figs. 87 and 93).—The allanto-enteric diverticulum arises early in the third week as a solid, entodermal outgrowth from the dorsi-caudal part of the yolk-sac and grows into the primary mesenchyme of the connecting stalk. It soon becomes canalicularised and when the hind-gut is developed, the proximal (enteric) part of the diverticulum is incorporated in its ventral wall and the distal (allantoic) portion is carried ventrally to open into the ventral aspect of the cloaca or terminal part of the hind-gut. The allantoic diverticulum is lined with entoderm and is surrounded by the mesenchyme of the connecting stalk, in which the umbilical vessels develop at a slightly later stage.*

FIG. 94.—A human embryo, 1.3 mm. long. (From a model by Eternod.)

The left wall of the yolk-sac and most of the amnion have been removed, and some of the primary mesenchyme of the connecting stalk has been cut away to show the allantois and the umbilical vessels. A portion of the chorion and some of the villi of the decidua basalis are shown.

The embryonic area is seen from the dorsal and left lateral aspects. Compare with fig. 85, which presents another view of the same model.



The **amnion** is a membranous sac which surrounds the embryo; it is developed in reptiles, birds, and mammals, but not in amphibia or fishes.

* In reptiles, birds, and many mammals the allantoic diverticulum expands into a vesicle which projects into the extra-embryonic coelom and forms a vascular organ to which the term *allantois* should be restricted. In the bird it projects to the right side of the embryo, and, gradually expanding, spreads over the dorsal surface of the embryo as a flattened sac between the amnion and the serosa, and ultimately surrounds the yolk. Its outer wall becomes applied to, and fuses with, the serosa which lies immediately inside the shell membrane. Blood is carried to the allantoic sac by the two allantoic or umbilical arteries, which are continuous with the primitive aortae, and after circulating through the allantoic capillaries, is returned to the primitive heart by the two umbilical veins. In this way the allantoic circulation, which is of the utmost importance in connexion with the respiration and nutrition of the chick, is established. Oxygen is taken from, and carbonic acid is given up to the atmosphere through the egg-shell, and nutritive materials are at the same time absorbed by the blood from the yolk. With the formation of the amnion the embryo is, in most animals, separated entirely from the chorion, and is not united to the chorion again until the allantoic mesenchyme spreads over and becomes applied to its inner surface; but the human embryo, as was pointed out by His, is never wholly separated from the chorion, its tail-end being from the first connected with the chorion by means of a thick band of mesenchyme, named the *connecting stalk*.

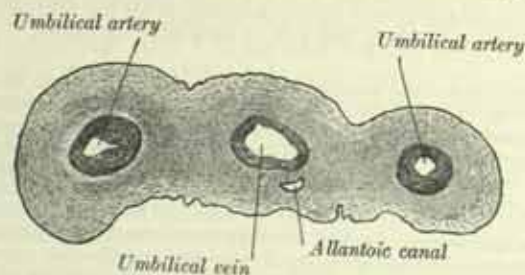
In the human embryo the amnion appears as a cavity between the formative mass and the trophoblast (p. 70). This cavity is roofed in by a stratum of flattened cells and its floor is formed by the cells of the embryonic germ-disc—the continuity between the roof and floor being established at the margin of the disc. On the outside the amnion is covered with a thin layer of primary mesenchyme, which is continuous, round the margins of the disc, both with the primary mesenchyme covering the yolk-sac and with the intra-embryonic mesoderm. Through the medium of the connecting stalk it is continuous also with the primary mesenchyme lining the chorion (fig. 89).

Fluid, termed *liquor amnii*, occupies the amniotic cavity and increases steadily in amount, so that the sac gradually expands and encroaches on the cavity of the extra-embryonic cœlom (fig. 91); this expansion continues until the extra-embryonic cœlom is obliterated entirely, except for a small portion which is included within the proximal part of the umbilical cord. The liquor amnii increases in quantity up to the sixth or seventh month of pregnancy, and then diminishes somewhat; at the end of pregnancy it amounts to 1 litre. It provides a buoyant medium to support the delicate tissues of the young embryo and it allows of the free movements of the fœtus during the later stages of pregnancy. It also diminishes the risk to the fœtus of injury from without. It contains less than two per cent. of solids, consisting of urea and other extractives, inorganic salts, a small amount of protein, and frequently a trace of sugar.

The connecting stalk and the umbilical cord.—The connecting stalk (figs. 88, 89, 91) is a mass of primary mesenchyme which at first connects the tail-end of the embryonic area with the chorion. Its proximal part surrounds the allanto-enteric diverticulum and it is traversed by the umbilical vessels. Its dorsal surface is covered with the amnion and its ventral surface is bounded by the extra-embryonic cœlom. As a result of the folding of the embryo and the distension of the amnion the connecting stalk comes to lie on the ventral surface of the embryo, and its mesenchyme approaches that of the yolk-sac and vitello-intestinal duct (fig. 89).

As a consequence of the continued expansion of the amnion the extra-embryonic cœlom is obliterated to a very large extent (fig. 91), and the only remaining part is the vitello-intestinal duct, and still communicates freely with the intra-embryonic cœlom. The mesenchyme-covered surfaces of the head, tail and lateral folds of the amnion converge on the region of the connecting stalk and the vitello-intestinal duct, and the umbilical cord is formed as they meet one another (figs. 88, 91). The cord consists of an outer covering of amnion, containing in its interior the vitello-intestinal duct, partially invested by the remains of the extra-embryonic cœlom and embedded in a mass of primary mesenchyme, contributed in part by the head and the lateral folds but, to a much greater extent, by the connecting stalk. The umbilical cord, therefore, incorporates within itself the connecting stalk and its contained umbilical vessels and the allantoic canal (figs. 94 and 95). The part of the extra-embryonic cœlom included in the umbilical cord acts as the sac for the normal umbilical hernia which characterises the embryo between

FIG. 95.—A transverse section through the umbilical cord.

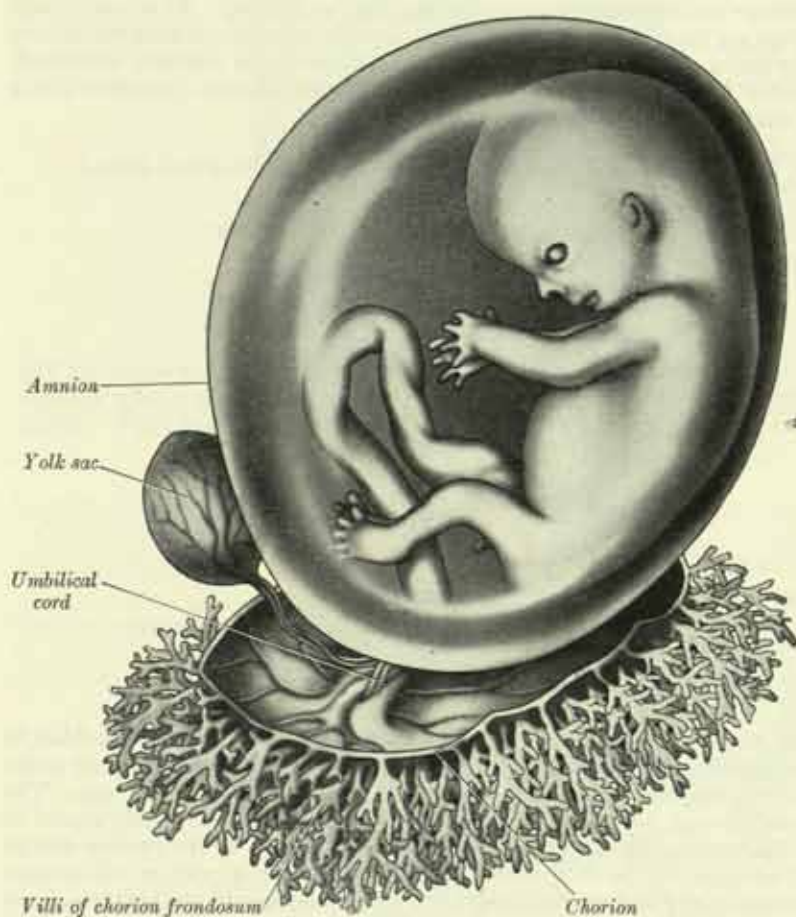


the sixth and the tenth weeks (p. 190). After the disappearance of this hernia the remains of the extra-embryonic cœlom normally become obliterated. The yolk-sac becomes caught between the amnion and the chorion as they fuse in the region of the placenta (figs. 91, 96 and 108) and it can sometimes be identified at term (p. 97).

The umbilical cord becomes spirally twisted, owing, it is believed, to the unequal growth of the two umbilical arteries; it also increases in length so that at the end of pregnancy it is about 50 cm. long. When fully developed the umbilical vessels, particularly the arteries, are provided with a strong muscular coat which contracts readily in response to mechanical stimuli. The outermost muscle bundles pursue an interlacing spiral course so that, when contracting, they produce shortening of the vessel and thickening of the media with folding of the interna and considerable narrowing of the lumen.

The implantation or embedding of the fertilised ovum in the uterine wall.—As already stated (p. 63), fertilisation of the ovum occurs in the lateral or

FIG. 96.—A foetus of about eight weeks, enclosed in the amnion, magnified by nearly $2\frac{1}{2}$ diameters. A portion of the chorion frondosum with its branching villi is shown in the lower part of the figure.

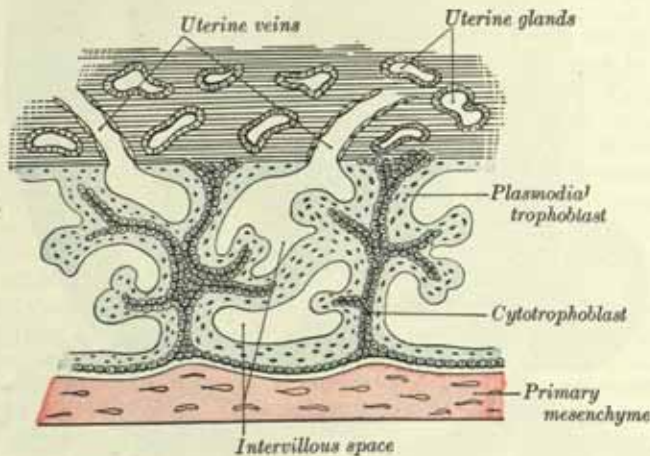


ampullary end of the uterine tube, and is immediately followed by segmentation. The segmenting ovum is conveyed along the uterine tube to the cavity of the uterus by the action of the cilia of the epithelial lining of the tube, the journey occupying about three days. On reaching the uterine lumen the ovum becomes a blastocyst but is still surrounded by the zona pellucida. The disappearance of the zona and the formation of plasmodial trophoblast over the region of the formative mass provide the prerequisite conditions for implantation in the uterine mucosa, so far as the ovum is concerned. In the interval between ovulation and the arrival of the blastocyst in the uterine cavity, changes occur in the uterine mucosa which prepare it for the reception of the ovum. These changes will be dealt with later. The necessary conditions preliminary to implantation having been fulfilled, the

plasmodial trophoblast adheres like a parasite to the uterine mucous membrane, destroys the epithelium over the area of contact, and excavates for the ovum a cavity in the mucous membrane in which it becomes embedded. In an ovum described by Bryce and Teacher * the point of entrance of the ovum into the uterine mucous membrane was visible as a small gap closed by a mass of fibrin and leucocytes; in an ovum described by Peters † the opening was covered with a mushroom-shaped mass of fibrin and blood-clot, the narrow stalk of which plugged the aperture in the mucous membrane. It is believed that this operculum represents a portion of the plasmodial trophoblast of the ovum which is cut off by the decidua capsularis (*vide infra*).

The structure actively concerned in excavating the uterine mucous membrane is the plasmodial trophoblast. This increases rapidly in thickness over the embryonic pole and forms over the rest of the wall of the blastocyst, as the ovum becomes embedded. It invades and digests the uterine tissues, and attacks the walls of the uterine (maternal) blood-vessels (fig. 70). Lacunar spaces develop in the trophoblastic envelope and establish communications with each other. At an early stage many of them are found to contain maternal blood (fig. 70) derived from the dilated uterine capillaries and veins, the walls of which have been partially destroyed. As the lacunar spaces enlarge, their trophoblastic walls become converted into a

FIG. 97.—Primary chorionic villi. Diagrammatic. (Modified from Bryce.)



spongework, the strands of which become invaded by columns of cytotrophoblast to form the *primary chorionic villi* (fig. 97). ‡ Some of these columns extend as far as the decidua, where they spread laterally to form the *trophoblastic shell* (fig. 99). The blood spaces between the primary villi expand to form what is ultimately known as the *intervillous space*. The inner wall of this space is formed by the chorion and its outer wall is formed by the shell of trophoblast (fig. 74). The primary villi acquire a core of mesenchyme and are thus converted into *secondary villi* (fig. 98) which are covered by a single layer of cytotrophoblast, which in turn is covered by a layer of plasmodial trophoblast. It is uncertain whether this mesenchymal core is derived from the primary mesenchyme of the chorionic vesicle or by differentiation from the more centrally situated cells of the cytotrophoblastic columns. The secondary villi give off numerous branches and at their outer ends their cytotrophoblast becomes continuous with the cytotrophoblast of the trophoblastic shell. The shell consists for the most part of cytotrophoblast, but it is covered on its inner surface by plas-

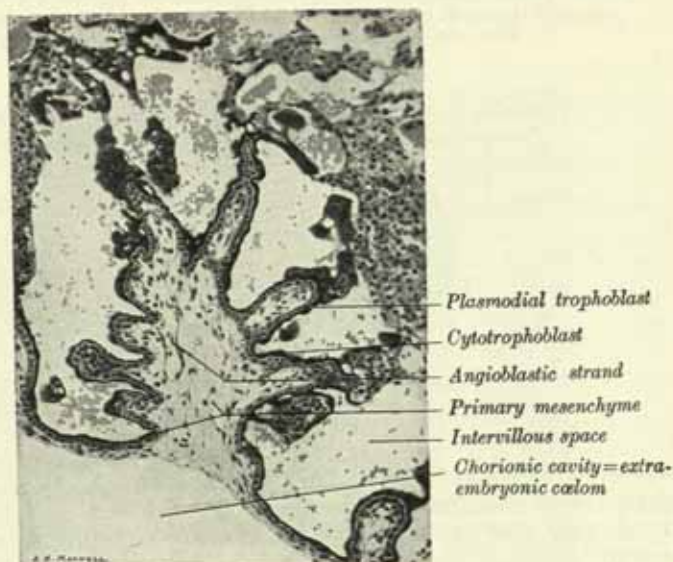
* Contribution to the study of the early development and imbedding of the human ovum, 1908.

† *Die Einbettung des menschlichen Eies*, 1899.

‡ The classification of the villi adopted here is that suggested by H. Stieve, *Morph. Jahrb.* 7, 1926.

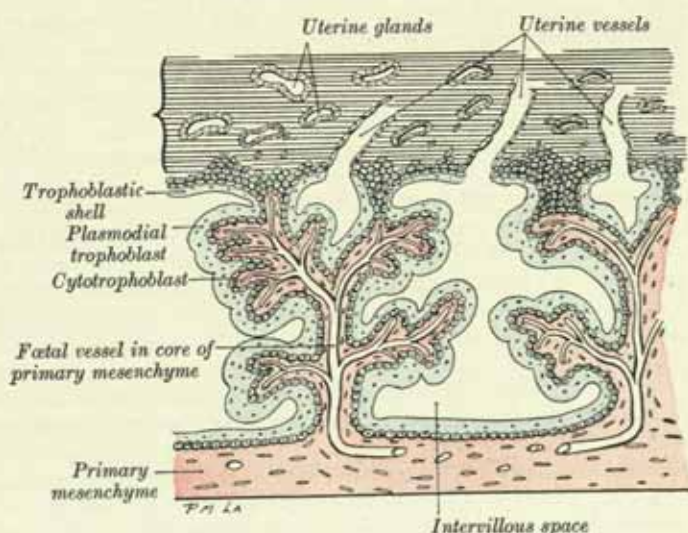
modium (fig. 99). As a result the blood-bathed walls of the intervillous space and of the villi are everywhere formed of plasmodial trophoblast. Finally, the secondary

FIG. 98.—A secondary chorionic villus. Drawn from a photomicrograph.



villi are converted into *tertiary villi* (fig. 100) by the development within them of vascular spaces which soon become linked up with the radicles of the umbilical vessels. Through the walls of these villi and of their contained capillaries

FIG. 99.—Tertiary chorionic villi. Diagrammatic.
(Modified from Bryce.)



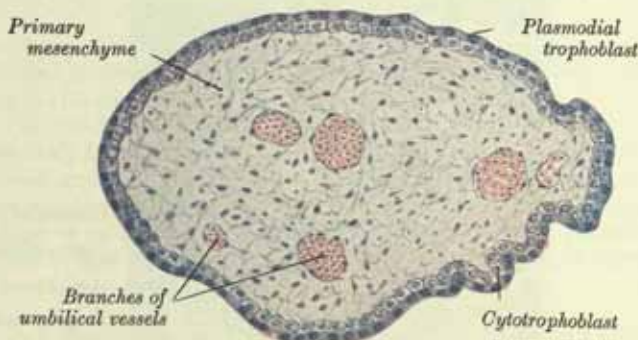
and oxygen pass to the fœtal circulation from the maternal blood in the intervillous space.

The plasmodial trophoblast which lines the intervillous space has been termed *resorptive trophoblast*,* as it is the medium by which nourishment is obtained for the

* J. Florian, *Erganzungsheft z. Anat. Anzeiger*, Bd. 66. 1928-9.

ovum from the maternal circulation. Plasmoidal trophoblast is found in other situations also, and especially around the periphery of the ovum where actively growing strands of plasmodium are responsible for the continued destruction of the uterine tissues. This variety is termed *proliferative trophoblast*, and its function is to enlarge the bed in which the ovum lies so as to provide for its increase in size.

FIG. 100.—A transverse section of a tertiary chorionic villus, stained with hæmatoxylin and eosin.



Wherever these strands of proliferative trophoblast break through the wall of a uterine blood-vessel and come into contact with the blood-stream, they tend to change their character and become transformed into the more passive resorptive variety.

Cyclical changes in uterus.—Throughout the period of fertility (i.e. from about the 15th to the 45th year), except during pregnancy and lactation, a series of closely related cyclical changes occur in the ovary, uterus and vagina. Each cycle extends over a period of about 28 days. In the ovarian cycle one follicle reaches full maturity, ruptures and releases its ovum during this period. The wall of the follicle is then transformed into an important endocrine structure, the *corpus luteum* (p. 1510). About 10 days after ovulation the corpus luteum begins to regress, then ceases to function and is replaced by fibrous tissue.

The cyclical changes in the uterus chiefly involve its lining mucosa, the *endometrium*, and constitute the menstrual cycle. This comprises four phases (a) *menstrual*, (b) *post-menstrual*, (c) *interval* and (d) *premenstrual*.

In the menstrual phase the superficial part of the endometrium, next to the free surface, is shed piecemeal, leaving only the basal portion, adjacent to the uterine muscle (fig. 101). Outwardly this phase is marked by a discharge of blood with necrotic epithelial debris from the uterus through the vagina. This discharge constitutes the *menstrual flow* and lasts a period of 3-4 days. In the postmenstrual phase, and even before the menstrual flow ceases, the epithelium from the persisting basal portions of the uterine glands grows outwards over the denuded surface of the endometrium. The endometrium is then 1-2 mm. in thickness and lined by a low cubical epithelium. The glands are straight and narrow. The stroma is dense and contains small numbers of lymphocytes amongst its spindle-shaped connective tissue cells (fig. 102).

During the interval phase there is a growth of the endometrium associated with the presence in the blood stream of *oestrogen*, an internal secretion produced by the ovary (fig. 106A). The endometrium thickens to about 2-3 mm. Mitoses are present and the glands become distinctly tortuous. Their lining epithelium becomes tall columnar (fig. 103). In the latter part of the interval phase clear spaces appear in the basal parts of the epithelial cells lining the glands (fig. 104). These vacuoles increase in size, occupy more of the cytoplasm and the nuclei are displaced from the basal regions of the cells towards the lumina of the glands. Secretion is exuded into the lumen and for a while the glands may be distended with secretion containing mucin and glycogen which can be demonstrated both in the cells and in the gland lumina with mucicarmine and Best's carmine stains. At the end of the interval phase no mitoses can be seen.

Ovulation occurs about 14 days before the onset of the next menstrual flow. The

changes which occur in the pre-menstrual phase are dependent upon the presence in the bloodstream of *progesterone* (fig. 106A) an internal secretion of the corpus luteum, in addition to *œstrogen*.

The premenstrual phase occurs during the 7 days immediately prior to the next

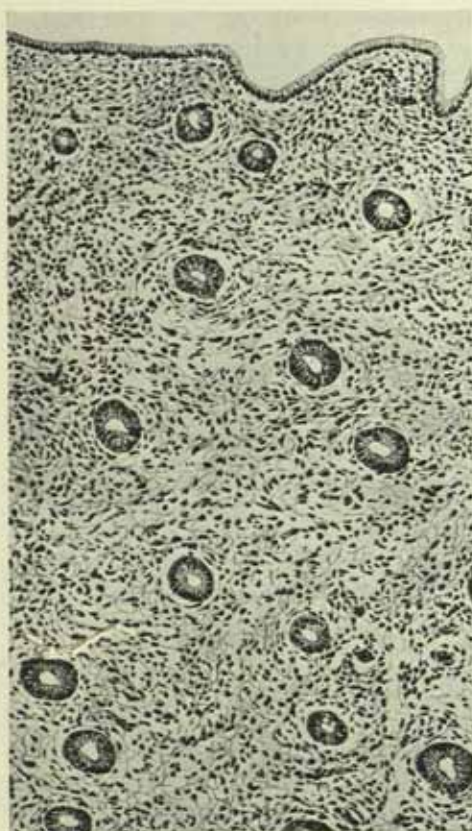
FIG. 101.—Section of a human endometrium during the menstrual phase. $\times 83$. Stained with hæmatoxylin and eosin. Kindly lent by the Shattock Museum, St. Thomas's Hospital Medical School.



menstrual flow. The mucous membrane becomes much thicker and at the end of the phase may be 7-8 mm. deep. In their middle portion, the glands become more voluminous and their walls are folded upon themselves so that tuft-like processes project into the lumen. This gives the glandular wall a saw-toothed appearance in longitudinal section. Secretion is seen in the lumen of the active parts of the gland.

The gland epithelium which was tall and columnar at the commencement of the phase becomes frayed and worn down in the aspect facing the lumen and the nuclei

FIG. 102.—Section of a human endometrium during the post-menstrual phase. $\times 120$. Stained with haematoxylin and eosin. Kindly lent by the Shattock Museum, St. Thomas's Hospital Medical School.



resume their original basal position. The basal parts of the gland adjacent to the uterine muscle take little or no part in these changes. In the later stages of the premenstrual phase characteristic changes appear in the stroma. These changes are especially seen in the superficial part of the endometrium and around the blood vessels. Here the stromal cells, hitherto not clearly defined from one another, are enlarged and swollen and for the first time definite cell outline can be clearly seen. A few mitoses may be seen in the stroma at this stage. The stromal changes constitute the premenstrual decidual reaction. The strata can now be clearly recognised in the endometrium (fig. 105):

1. *Stratum compactum*, next to the free surface in which the necks of the gland are but slightly expanded and the stromal cells show a distinct decidual reaction.

2. *Stratum spongiosum*, where the uterine glands are tortuous, dilated and ultimately separated from one another by a small amount of interglandular tissue.

3. A thin *stratum basale*, next to the uterine muscle containing the tips of the uterine glands embedded in an unaltered stroma.

In the last days of the premenstrual phase lymphocytes appear in the endometrium in increasing

numbers. They are found between and beneath the surface epithelial cells, amongst the stromal cells and around and between the gland cells. Towards the end of this period, with regression of the corpus luteum, those parts of the stroma showing decidual reaction and gland epithelium undergo degenerative changes as shown by their poor staining reaction. The endometrium may diminish in thickness. These degenerative changes in the endometrium precede the bleeding.

During menstruation blood escapes from the blood vessels in the superficial strata of the endometrium. Small haematomata form beneath the surface epithelium and raise it up. Blood and necrotic endometrium appear in the uterine lumen. The amount of tissue lost is variable, but usually the stratum compactum and most of the spongiosum is desquamated. The shedding of the endometrium starts at the surface and extends into the deeper parts.

The endometrium is regenerated from the stratum basale and that part of the spongy layer which remains. The surface epithelium is reformed with remarkable rapidity.

The vascular bed of the endometrium undergoes significant changes during the menstrual cycle. The arteries to the endometrium arise from a plexus in the muscular coat and consist of short straight vessels to the basal portion of the endometrium and more muscular-walled arteries to its superficial two-thirds. The venous drainage consists of narrow perpendicular vessels which anastomose by cross branches and is common to both the superficial and basal layers of the endometrium. The arterial supply to the basal part of the endometrium remains unchanged during the menstrual cycle. The spiral arteries to the superficial strata, however, lengthen

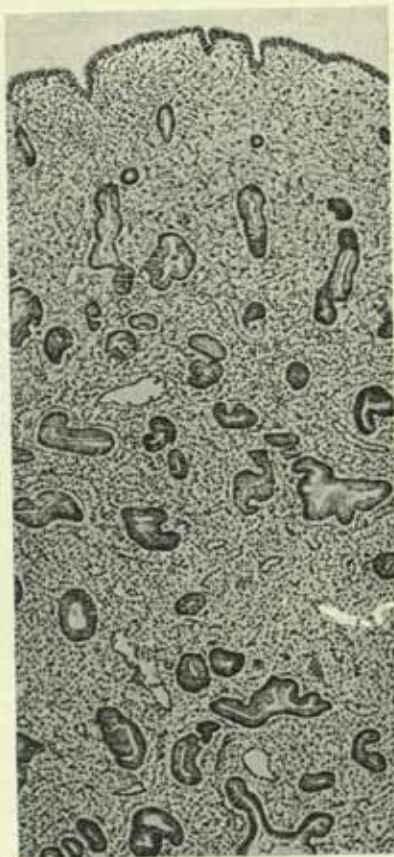
disproportionately, become increasingly coiled and their tips approach more closely to the uterine epithelium during the interval and more markedly in the premenstrual phase of the menstrual cycle. This leads to a slowing of the circulation in the superficial strata with some vasodilation. Immediately before the menstrual flow these vessels begin to constrict intermittently causing stasis of the blood and anaemia of the superficial strata. During the periods of relaxation of the vessels blood escapes from the damaged capillaries and veins, thus causing the menstrual haemorrhage.

The changes in the endometrium leading to the hypertrophy of the premenstrual phase are a preparation of the endometrium for the reception of the fertilised ovum and result from the action of oestrogen and progesterone (fig. 106A). If fertilisation of the ovum in question does not occur, the corpus luteum undergoes degenerative changes and progesterone is no longer secreted. The inference is always that the history of the corpus luteum depends rather on embedding of the ovum. The effect of the absence of progesterone, together with the simultaneous diminution in the amount of oestrogen in the blood renders the uterine mucosa unstable and about 12 to 16 days after ovulation some of the dilated vessels break down, patches of uterine epithelium become necrotic and a new menstrual flow begins. The cycle comprises a pre-ovulatory and a post-ovulatory phase, which are of approximately equal duration, although there is a tendency for the pre-ovulatory phase to be more variable than the post-ovulatory phase.

Menstruation frequently occurs in the absence of ovulation, particularly around puberty and in women approaching the menopause. Instead of liberating its ovum, the ripe follicle fails to rupture and undergoes degeneration. This is accompanied by a rapid reduction in oestrogen secretion with consequent breakdown of the uterine mucosa in the interval phase and in the absence of the changes evoked by the presence of progesterone in the blood stream.*

The decidua.—If fertilisation takes place, the corpus luteum continues to function actively, the secretion of progesterone goes on uninterrupted (fig. 106B), menstruation does not occur, and the thickened and vascular mucous membrane, which is now known as the *decidua*, is ready for the reception and embedding of a fertilised ovum. In addition the interglandular tissue is increased in quantity; it contains a number of leucocytes, and is crowded with large round, oval or polygonal cells termed *decidual cells*. These are connective tissue cells of the endometrium which have accumulated glycogen or lipoids. They are conspicuous in the early stages of gestation but tend to disappear in the later months. Their precise significance is uncertain. Possibly they offer pabulum which attracts the proliferative trophoblast but, on the other hand, they are often regarded as a defensive mechanism to protect the endometrium from excessive destruction. These changes are well advanced by the second month of pregnancy, when the three strata recognisable in

FIG. 103.—Section of a human endometrium during the interval phase. $\times 53$. Stained with haematoxylin and eosin. Kindly lent by the Shattock Museum, St. Thomas's Hospital Medical School.

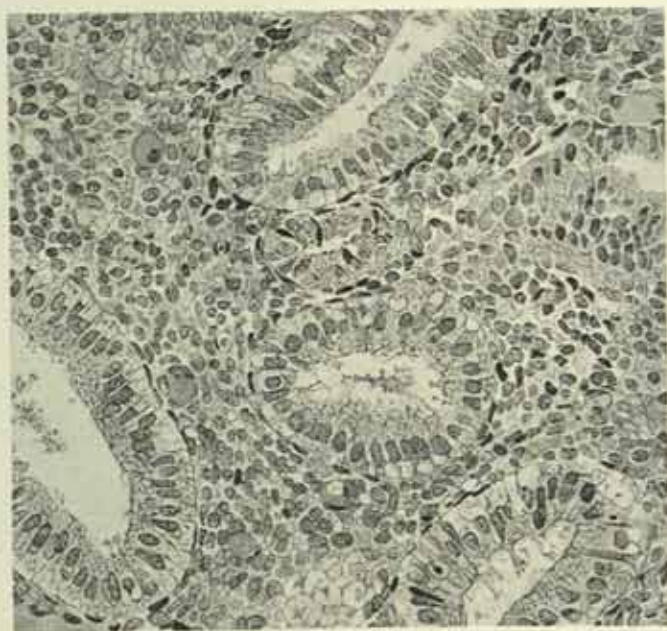


* G. W. Corner, *Amer. J. Physiol.*, 124, 1938.

the premenstrual phase, the stratum compactum, stratum spongiosum and stratum basale are better differentiated and easily distinguished.

After the ovum is embedded, distinctive names are applied to different portions of the decidua. The part which covers the ovum is named the *decidua capsularis*; the

FIG. 104.—Section of a human endometrium at about the seventeenth day of the menstrual cycle to show the accumulation of secretions in the basal parts of the epithelial cells lining the glands, resulting in displacement of the nuclei towards the lumen of the gland. $\times 300$. Stained with hæmatoxylin and eosin. Kindly lent by the Shattock Museum, St. Thomas's Hospital Medical School.



portion between the ovum and the uterine muscular wall is named the *decidua basalis*, and it is here that the placenta is subsequently developed; the part which lines the remainder of the body of the uterus is known as the *decidua parietalis* (fig. 108).

Coincidentally with the growth of the embryo and the expansion of the cavity of the amnion (p. 88), the decidua capsularis is thinned and distended (figs. 107 and 108) and the space between it and the decidua parietalis is gradually obliterated. By the beginning of the third month of pregnancy the decidua capsularis and decidua parietalis are in contact; by the fifth month the decidua capsularis has practically disappeared, while during the succeeding months the decidua parietalis also atrophies, owing to the increased pressure. The glands of the stratum compactum are obliterated, and their epithelium is lost; in the stratum spongiosum the glands are compressed and appear as slit-like fissures, and their epithelium undergoes degeneration; in the limiting or boundary layer, however, the glandular epithelium retains a cubical form.

The **chorion** (figs. 86 to 92 and 97 to 99) consists of an outer layer of trophoblast, and an inner of primary mesenchyme (p. 71). As already stated (p. 90), the trophoblast undergoes rapid proliferation and forms, on the surface of the chorion, a succession of processes which are known as the *primary, secondary and tertiary chorionic villi* (figs. 97-99). Blood is carried from the embryo to the chorion by the umbilical arteries, and, after circulating through the capillaries of the chorionic villi, is returned to the embryo by the umbilical veins. From the third week until about the end of the second month of pregnancy the entire chorion is covered with villi which project into the decidua basalis and decidua capsularis (fig. 108). Those of the decidua basalis are longer and show more numerous branches than those of the decidua capsularis. With the growth of the embryo and the expan-

sion of the amniotic cavity the decidua capsularis is thinned and compressed, the circulation through it is gradually cut off, and the villi of the corresponding part of the chorion atrophy and disappear. This portion of the chorion becomes smooth (*chorion laeve*); and, as it takes no share in the formation of the placenta, is sometimes named the non-placental part of the chorion. On the other hand, the villi on that part of the chorion which is in contact with the decidua basalis increase greatly in size and complexity, and hence this part is named the *chorion frondosum* (figs. 89, 108). It constitutes the placental area and here the intervillous space becomes expanded at the expense of the stratum compactum and the superficial part of the stratum spongiosum.

The **placenta** (figs. 108 to 110) connects the foetus to the uterine wall and both foetal and maternal tissues share in its formation. It is the organ by means of which the respiratory, nutritive and excretory functions of the foetus are performed.

The separation of the placenta.—After the child is born, the placenta becomes separated from the uterine wall and, together with the 'membranes,' is expelled as the *after-birth*. Separation takes place along the plane of the stratum spongiosum and extends beyond the placental area so as to detach almost the whole thickness of the decidua parietalis, remains of the decidua capsularis, chorion laeve and amnion, which have become fused with it. These three layers are continuous with the placenta at its margin and they constitute the 'membranes'. The process of separation necessarily causes rupture of uterine vessels but their torn ends are closed by the firm contraction of the muscular wall of the uterus and thus, under normal circumstances, post-partum hæmorrhage is limited in amount. When the after-birth has been expelled, a thin layer of the stratum spongiosum is left as a lining for the uterus but it undergoes degeneration and is cast off in the early part of the puerperium. The mucous membrane, the glands and the epithelial lining of the uterus are regenerated from the limiting or boundary layer (p. 96) of the decidua.

Macroscopic appearances.—The expelled placenta is a discoid mass which weighs about 500 gm. Its diameter varies from 15–20 cm. and its depth from 3–4 cm. near its centre, rapidly diminishing towards the periphery. Its *foetal or inner surface*, which is covered by the amnion, is smooth and transparent so that the mottled appearance of the chorion can be seen through it. The umbilical cord is usually attached near the centre of the foetal surface and the branches of the umbilical vessels radiate out under the amnion from this point, the veins being deeper and larger than the arteries. Beneath the amnion and close to the attachment of the umbilical cord, the remains of the yolk-sac can sometimes be identified as a minute sac with a fine thread—a vestige of the vitello-intestinal duct—attached to it.

The *maternal or outer surface* is finely irregular in appearance and is mapped out into from 15 to 30 areas by a series of fissures or grooves. These areas are the

FIG. 105.—Section of the whole thickness of human endometrium in the premenstrual phase. Note the irregular saw-toothed appearance of the walls of the glands and the frayed appearance of the epithelial cells. $\times 60$. Stained with hæmatoxylin and eosin. Kindly lent by the Shattock Museum, St. Thomas's Hospital Medical School.



bases of the lobules or *cotyledons* and from the grooves between them incomplete septa extend into the substance of the placenta.

Microscopic appearances.—The foetal surface is covered with a single layer of

FIG. 106 (A).—Graphic representation of the menstrual cycle in the absence of fertilisation.

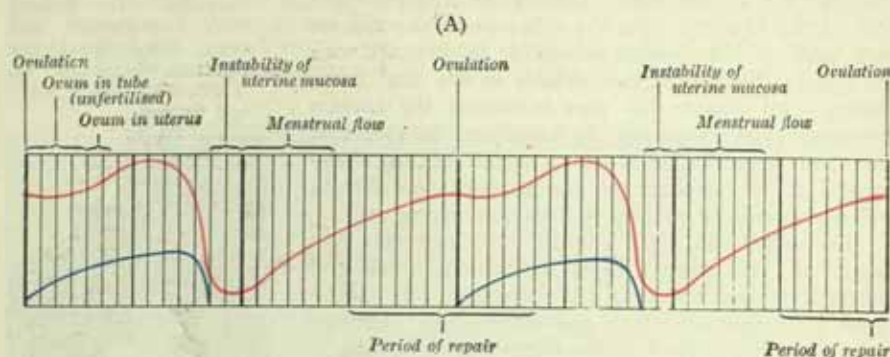
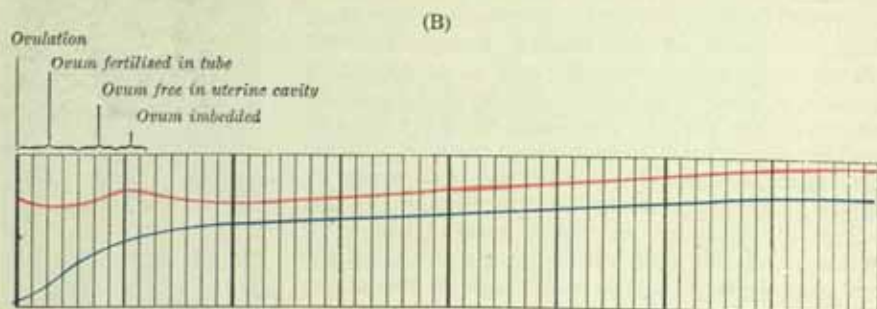


FIG. 106 (B).—Graphic representation of the same period when the ovum is fertilised.



Note.—Each vertical line represents a day, every seventh day being indicated by a heavy line. The red lines show the graphs of the secretion of estrogenic substances, and the blue lines show the graphs of progesterone secretion.

epithelium of the amnion—not always easily recognisable—beneath which the primary mesenchyme of the amnion and chorion are continuous with each other and enclose the larger branches of the umbilical vessels. The cytotrophoblast of the chorion, which shows occasional patches of syncytial trophoblast, forms the inner wall of the deep *intervillous space*, which is filled with maternal blood.

From the outer wall of the intervillous space the placental septa extend almost to the inner wall so that the individual cotyledons are shut off from one another except near the chorion, where they communicate freely. These septa are non-vascular and consist of trophoblast and fibrinoid substance. In each cotyledon a large *stem villus* extends from the inner to the outer wall of the intervillous space and contains one or more relatively large branches of the umbilical artery and vein. At its extremity each stem villus is anchored to the trophoblast of the outer wall, but it gives origin to a large number of branching villi which project into the intervillous space.

At first most of the branches of the stem villi are free (fig. 108) but, after the second month, more and more of them become connected to one another and to the outer and inner walls of the intervillous space. It is, however, doubtful whether these connexions are more than adhesions, although the covering trophoblast disappears and their mesenchymal cores become continuous. As a result, the whole framework of the placenta is converted into a sponge in the meshes of which the maternal blood can only circulate slowly.* This has been named the *villous type* of the *labyrinthine haemochorial placenta*.

* H. Stieve, *Z. f. mikr.-Anat. Forsch.*, 48, 1940.

The outer wall of the intervillous space, termed the *basal plate*, is formed by the deeper part of the stratum spongiosum, some fibrinoid substance and cytotrophoblast and so is partly maternal and partly foetal in origin. Numerous branches from the coiled arterioles of the decidua pierce the basal plate and keep the intervillous space filled with maternal blood. These vessels lose their muscular coats as they enter the plate and their sinuous, terminal portions are lined only with endothelium.

The veins which drain the blood away from the intervillous space pierce the basal plate and join tributaries of the uterine veins. The presence of a marginal sinus, which has hitherto been described as a constant feature, occupying the peripheral margin of the placenta and communicating freely with the intervillous space, has not been confirmed on examination of a series of placentae, at varying stages, fixed and cut *in situ*.*

Growth and functions of the placenta.—In the early stages of placental development the blood in the foetal vessels is separated from the maternal blood in the intervillous space by their lining endothelium, the mesenchyme of the villus and the covering cyto- and syncytial trophoblast (fig. 100). In this way a barrier is interposed between the two blood currents

FIG. 107.—Diagram showing a young ovum embedded in the uterine decidua near the fundus.

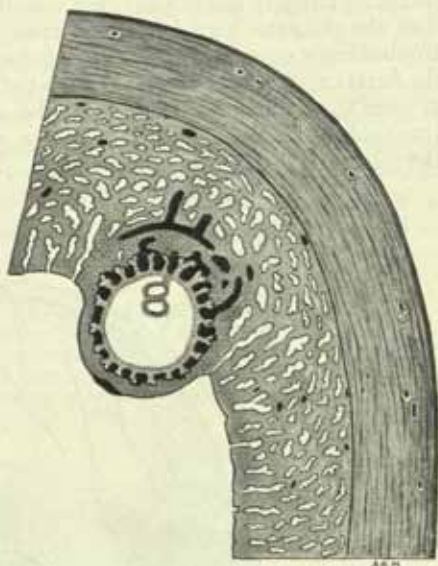
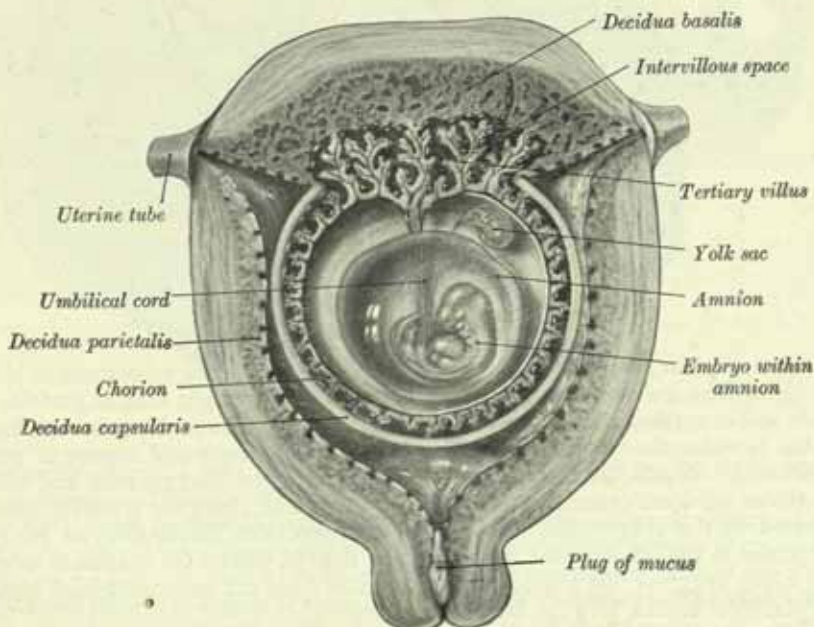


FIG. 108.—A sectional plan of the gravid uterus in the second month.

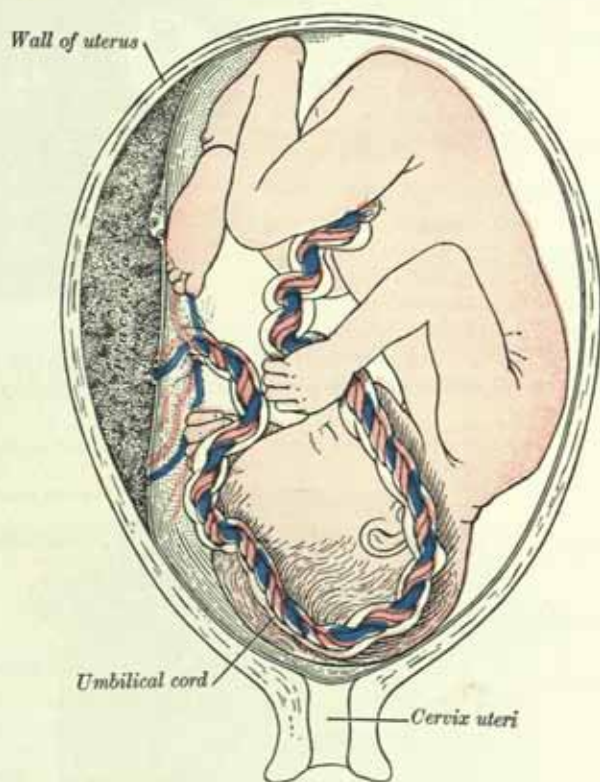


but it is a permeable barrier and allows water, oxygen and other nutritive substances, and hormones to pass from the mother to the foetus and some

* W. J. Hamilton and J. D. Boyd, *Proc. Roy. Soc. Med.*, 44, 1951, and H. Stieve, *Anat. Anz.*, 96, 1948.

of the products of excretion to pass from the fœtus to the mother. During the first half of pregnancy the placenta not only increases its surface area, but reaches its maximum thickness. The growth in depth results from increase in the size and length of the stem villi, and is not accompanied by any further invasion of the uterine wall. In the latter half of pregnancy the placenta increases its surface area and doubles its diameter, but it does not increase in thickness.* It therefore tends to fail to keep pace with the growth of the foetus, but, in compensation, the placental barrier becomes reduced in thickness. After the fifth month the trophoblastic covering of the villi becomes reduced to a thin layer of syncytium and the foetal capillaries approach close to the surface of the villus (fig. 111). As a result, at term the foetal and maternal blood-currents are separated only by the syncytial trophoblast and the endothelium. The mechanism of transfer of substances across the placental barrier is complicated. The accepted physico-chemical concepts

FIG. 109.—A fœtus in utero, between the fifth and sixth months.



suffice to explain gaseous exchange and the transfer of many substances in simple solution. The transfer of substances of high molecular weight such as proteins and lipids and of antibodies is not so readily understood.† The problem is complicated by the fact that the trophoblast itself is the site of synthesis and storage of certain substances. Recent histochemical investigations suggest that proteins and steroid hormones are synthesized by the syncytium and that chorionic gonadotrophin is secreted by the cytotrophoblast. It may be noted also that leucocytes are more numerous in the blood of the umbilical vein than in that of the umbilical artery, a fact which suggests that leucocytes may migrate from the maternal blood, through the placental barrier into the foetal capillaries.

* W. J. Hamilton and J. D. Boyd, *Proc. Roy. Soc. Med.*, **44**, 1951, and H. Stieve, *Anat. Anz.*, **96**, 1948.

† Sir Joseph Barcroft, "Researches on Pre-natal Life," 1946. Blackwell Scientific Publications Ltd., Oxford. A. St. G. Huggett and J. Hammond in Marshall's *Physiology of Reproduction*, Vol. 2, edited by A. S. Parkes, 1952.

Site of placental attachment.—As a rule the placenta is attached to the posterior wall of the uterus near the fundus, with its centre in or near the median plane. The site of attachment is determined by the point where the blastocyst becomes embedded and the factors on which the precise point depends are not yet fully understood. The placenta, however, may be attached at any point on the uterine wall, but these variations offer no complications to a normal labour unless the placenta is attached so low down that it overlies the internal os uteri, when it may give rise to serious hæmorrhage, especially if it is nearly central in position. This condition, which occurs in about 0.5 per cent. of cases, is known as *placenta prævia*.

The umbilical cord, although usually attached near the centre of the organ, may reach it at any point between its centre and its margin. In the latter event it is known as a 'battledore' placenta. Occasionally the cord fails to reach the placenta itself and ends in the membranes in its vicinity. This is termed the *velamentous insertion* and the larger branches of the umbilical vessels traverse the membranes before they reach and ramify on the surface of the placenta. A small accessory or

FIG. 110.—The foetal surface of a recently delivered placenta, drawn from a coloured photograph, given to the editors by Mr. E. F. Gibberd.

The maternal surface is exposed in the lower and right corner of the figure. Note the small branches of the uterine artery and the series of grooves. Note also the amnion and chorion which have been cut away near the placental margin.



succenturiate placental lobe is occasionally present connected to the main organ by membranes and blood vessels.

At birth, when ligature of the umbilical cord is delayed, the blood volume of the child is, on the average, appreciably greater than it is when the ligature is applied at the earliest possible moment.* It appears that in the former case most of the blood in the foetal placental vessels is transferred from the placenta to the foetus. The meaning of the phenomenon is far from clear, for in the first few days of life after late ligature of the cord the newly born suffers a loss both of plasma volume and of hæmoglobin.†

* Q. B. de Marsh, W. F. Windle and H. L. Alt, *Amer. J. Dis. Child*, 63, 1942.

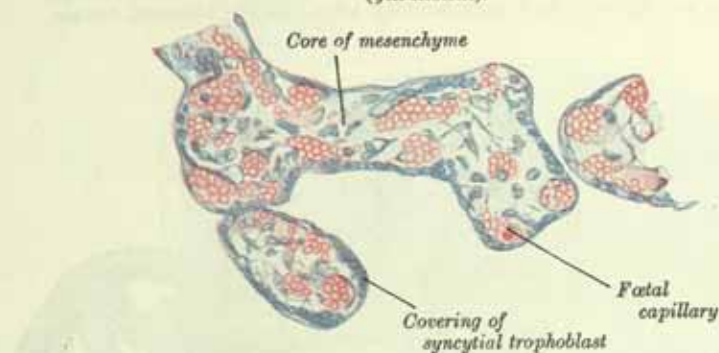
† T. Gotser, *J. Physiol.*, 94, 1939.

The Phylogeny of the Placenta.*—"The mammalian placenta is an apposition or fusion of the foetal membranes to the uterine mucosa for physiological exchange."†

The true chorion is avascular and in the mammals either the yolk sac or allantois or both may establish a functional connexion with the chorion to form a chorio-vitelline or chorio-allantoic type of placenta. The so-called chorion of most eutherian mammals is in fact an allanto-chorion and is vascularised by the allantoic vessels and the principal pathway for the transfer of material between the mother and foetus is usually a chorio-allantoic placenta. In man the placenta is regarded as allantoic in origin and the body stalk as the homologue of the allantois in which the endodermal vesicle is vestigial, and the umbilical vessels represent the allantoic vessels.

The degree of intimacy of fusion or apposition of the allanto-chorion with the uterine mucosa varies in different mammals. It seems probable that in the ancestral viviparous mammals the relation of the allanto-chorion to the uterine mucosa was one of apposition and not fusion, and the type of placentation is termed *epithelio-chorial*. Probably the whole of the outer surface of the chorion was implicated and the placenta was therefore *diffuse* as opposed to discoidal placenta found in man. Such a diffuse epithelio-chorial placenta is found in some present-day mammals. Some authorities regard this as a reversion to the primitive type and not as a persisting primitive feature. As the relationship between the maternal and foetal tissues is one of contact

FIG. 111.—Part of a section of a branching villus in a mature placenta (9th month).



only no part of the uterine mucosa is shed at term and the placenta is therefore termed *non-deciduate*.

Fusion of the trophoblast covering the allanto-chorion with the uterine epithelium results in the disappearance of the latter and gives rise to the *syndesmochorial* type of placentation in which the maternal blood stream remains separated from the chorion by its vascular endothelial walls and the surrounding fibro-areolar tissue.

Disappearance of the ensheathing fibro-areolar tissue—the next stage in placental development—brings the maternal vascular endothelium in direct contact with the trophoblast of the allanto-chorion, producing an *endothelio-chorial* type of placentation which may be restricted to a broad band around the transverse axis of the chorion—the *zonary* as opposed to the diffuse and the discoidal forms.

Lastly the disappearances of the maternal vascular endothelium brings the maternal bloodstream into direct contact with the trophoblast of the allanto-chorion and gives rise to the haemochorial type of placentation. This is the type seen in man and most primates.

The above classification, based on the degree of approximation of the foetal and maternal bloodstreams forms a useful guide in physiological considerations of the transfer of materials between the mother and the foetus. It must be remembered, however, that in some mammals a chorio-vitelline placenta may also be present. In some cases the uterine blood vessels may even penetrate the uterine epithelium. Furthermore, the placental barrier may vary in its structure at different stages and tends to become attenuated with the advance of pregnancy. Thus in the late placenta of some rodents, in which the relationship was originally haemochorial, only the endothelium of the foetal blood vessels may remain in places to separate the maternal

* G. B. Wislocki, *Contr. Embryol.*, Carneg. Instn., **20**, 1937; J. P. Hill, *Phil. Trans. Roy. Soc.*, London, B, **221**, 1932; O. Grosser, *Verhandl. Anat. Gesellsch.*, **81**, 1936; H. W. Mossman, *Contr. Embryol.*, Carneg. Instn., **26**, 1937; E. C. Amoroso, *Placentation*. Marshall's *Physiology of Reproduction*, loc. cit.

† H. W. Mossman, loc. cit.

and foetal blood streams. This relationship is termed *haemoendothelial*. Finally, some chorio-allantoic placentae combine the different structural types and it has been maintained that the syndesmo-chorial relationship, seen only in the bovine placenta, occurs over a very limited area.

On the basis of their architecture two varieties of placenta can be recognised. In the commoner and probably more primitive *labyrinthine* variety the trophoblast forms a fine meshwork with many intersecting strands. The strands of the meshwork usually possess fine cores of mesenchyme surrounding the chorionic capillaries. In the *villous* variety, which occurs only in haemochorial placentae, the intersecting strands are lost and the chorionic villi dip into or cross the intervillous space.

The placenta of the platyrrhine monkeys is labyrinthine, haemochorial in type but in the catarrhine monkeys it displays features of both the labyrinthine and villous varieties and may be regarded as transitional in character. The villous haemochorial placenta is found in the anthropoid apes and man.

THE DEVELOPMENT OF THE INDIVIDUAL SYSTEMS

The development of the embryo has already been traced to a stage at which the process of differentiation becomes so complicated that it is no longer possible to deal with the embryo as a whole. At this stage the embryo, which is about $3\frac{1}{2}$ weeks old, is only partly constricted off from the yolk-sac. The head and tail-folds have formed, with the resultant enclosure of the fore-gut and the hind-gut. The projection caused by the fore-brain is now the cephalic end of the embryo, and the oral membrane and the pericardium lie caudal to it on the ventral aspect. The secondary mesoderm has differentiated to a certain extent, and its paraxial portion is undergoing segmentation with the resultant formation of mesodermic somites. The neural groove is in process of closure to form the neural tube and it is separated from the dorsal wall of the gut by the notochord. The earliest blood-vessels have been laid down and a primitive tubular heart is present in the pericardium. The chorionic circulation will shortly be established and thereafter the embryo will derive all the nourishment which it requires from the maternal blood. The intra-embryonic coelom comprises the pericardium, the right and left pericardioperitoneal canals, which lead tailwards from its dorsal aspect, and the peritoneal cavity, into which the pleuroperitoneal canals open caudal to the septum transversum and so establish free communication with the extra-embryonic coelom (fig. 84).

Henceforth it is necessary to deal with the development of the various systems and organs independently of one another, but, in the pages that follow, it will frequently be necessary to refer back to the stage which has just been summarised.

THE DEVELOPMENT OF THE SKELETAL SYSTEM

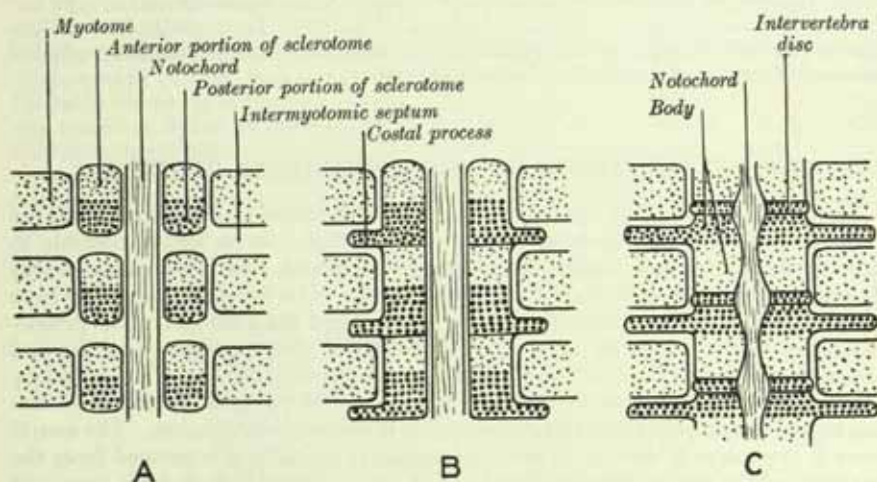
The **skeleton** is of mesenchymal origin, and most of its parts pass through, first, a membranous or blastemal stage, and then a cartilaginous stage before they become ossified. In some bones, however, the process of ossification follows immediately on the membranous stage, and the stage of chondrification is omitted.

The vertebral column.—Before it reaches its final condition the central axis of the body passes through no fewer than three preliminary stages. In the first place it is formed by the non-segmented notochord (p. 75), a flexible rod of cells enclosed within a stout membranous sheath. This structure, however, is not limited to the region in which the vertebral column is laid down, but extends into the region of the head as far as the caudal aspect of the hypophysis, and is subsequently incorporated in the basilar portion of the occipital bone and the posterior part of the body of the sphenoid (fig. 116).

The notochord acts as a framework around which the sclerotogenous tissue derived from the sclerotomes (p. 79) builds up a *blastemal* or *mesenchymal vertebral column*, consisting of thirty-five or more segmental units, which are termed *proto-vertebrae*. Fusiform cells from the sclerotomes migrate ventrally and medially on each side (fig. 83) and enclose the notochord in a mass of mesenchyme, which outlines the vertebral centrum. Coronal or sagittal sections passing through the blastemal column show that the cells are more closely packed together in the caudal

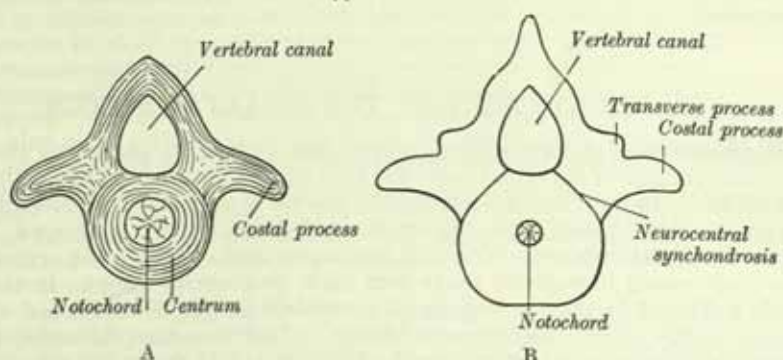
half of each protovertebra and more loosely arranged in its cephalic half (fig. 112). From the darker, caudal portion of the protovertebra an extension grows dorsally on each side of the neural tube to outline the neural arch, and another extension grows laterally into the interval between the corresponding myotome and the one caudal to it, to outline the costal process. While these extensions are appearing, the darker caudal half of each protovertebral centrum fuses with the lighter, cephalic half of

FIG. 112.—A scheme showing the manner in which each vertebral body is developed from portions of two adjacent segments.



the one caudal to it. In this way the segmental protovertebrae give place to *blastemal vertebrae*, each of which is formed from portions of two adjoining segments and retains connexion with the lateral and dorsal outgrowths from its cephalic half. As no further change in position occurs during the ensuing periods of chondrification and ossification, it follows that the intervertebral discs of the adult are segmental in origin, whereas the vertebral bodies comprise portions of two adjoining segments

FIG. 113.—Diagrams showing (A) the blastemal and (B) the cartilaginous stages of a typical vertebra.



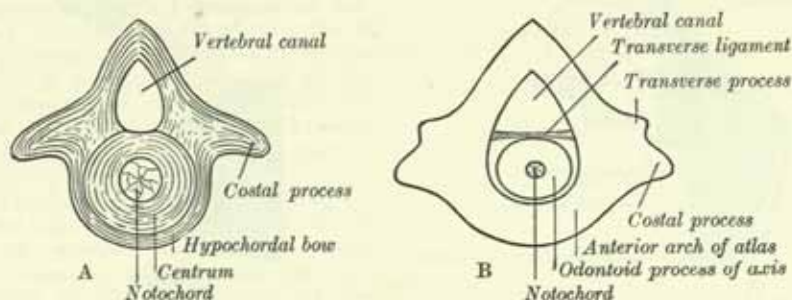
and the intersegmental tissue between. The intersegmental vessels which lay opposite the intervals between the protovertebrae now lie opposite the vertebrae, a topographical relationship which persists in the adult in the lumbar and lower thoracic regions.

The third stage in the development of the central axis of the body commences in the seventh week with the appearance of centres of *chondrification* in the blastemal vertebrae and their neural arches and proceeds to the formation of a *cartilaginous vertebral column*. Two centres of chondrification appear in the caudal half of each blastemal vertebra and fuse to form the cartilaginous *centrum*. Independent centres

appear in each half of the neural arch and in each costal process. In the former, chondrification extends forwards into the pedicles and backwards into the laminae, but the two laminae do not meet and fuse with one another until the fourth month of intrauterine life. The centre of chondrification in the costal process extends both laterally and medially and soon fuses temporarily with the centrum of the vertebra. This continuity does not last long and disappears as the costocentral joint becomes defined. Later, chondrification extends laterally from the neural arch to outline the transverse process, which lies dorsal to the costal process (figs. 113A and B).

Special reference must be made to a structure which, although present in the blastemal period, only becomes recognisable as a separate entity subsequent to chondrification. This structure is named the **hypochordal bow**. It connects the vertebral ends of the two costal processes to each other across the ventral surface of the centrum (fig. 114), and, it should be observed, is only found in connexion with the upper three or four cervical vertebrae. In the case of the atlas alone the hypochordal bow persists, chondrifies, and becomes ossified during the first year to form its anterior arch and the anterior ends of its lateral masses. In the cases of the succeeding vertebrae the hypochordal bow undergoes degeneration, and subse-

FIG. 114.—Diagrams showing the transformation of the hypochordal bow into the anterior arch of the atlas.



quently either disappears in its entirety or becomes incorporated in the anterior part of the centrum.

The notochord can be identified for some time traversing the centra of the cartilaginous column. Ultimately the portions within the centra atrophy and disappear, but the portions in the intervertebral discs are said to expand and persist throughout life as the *nucleus pulposus* of each disc (p. 463).

Towards the end of the second month of intrauterine life centres of ossification appear in the cartilaginous vertebrae, and the vertebral column enters on its fourth and last stage, viz. that of ossification. The details of this process are described on p. 248.

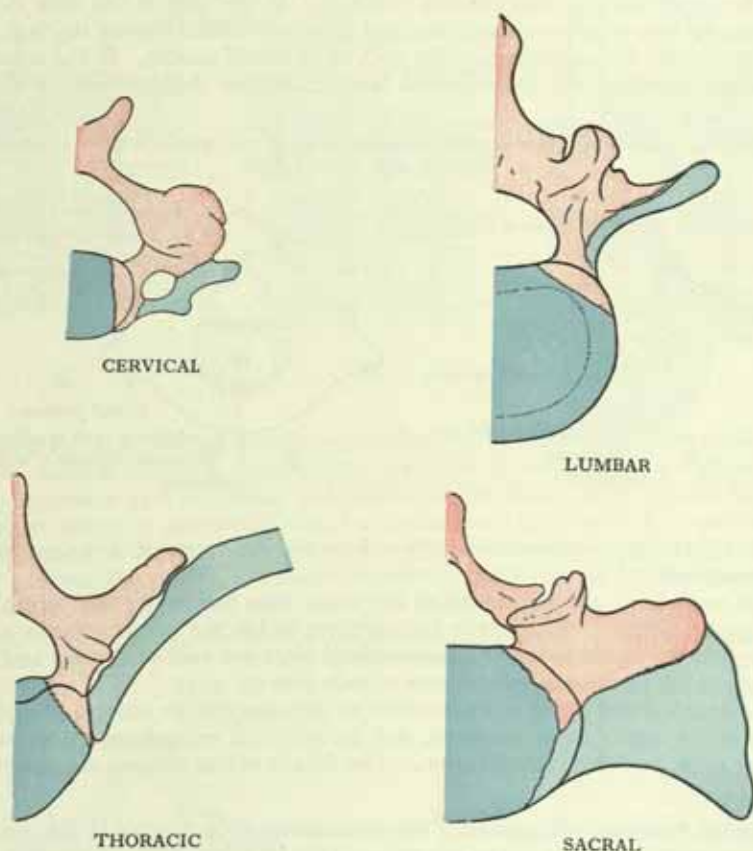
Applied Anatomy.—Occasionally the coalescence of the laminae is not completed, and consequently a cleft is left in the arches of the vertebrae, through which a protrusion of the spinal membranes (dura mater and arachnoid), and generally of the spinal medulla and pia mater, takes place, constituting the malformation known as *spina bifida*. This condition is most common in the lumbosacral region, but it may occur in the thoracic or cervical region, or the arches throughout the whole length of the canal may remain incomplete.

The ribs.—The ribs are formed from the costal processes of the primitive vertebral arches, the processes extending between the muscle-plates. In the thoracic region of the vertebral column the costal processes grow laterally to form a series of arches termed the *primitive costal arches*. The transverse process grows out behind the vertebral end of the costal process, and is at first connected to it by mesenchyme which is later differentiated to form the ligaments of the costotransverse joint; between the costal process and the tip of the transverse process the costotransverse joint is formed, while the proximal end of the costal process becomes separated from the neural arch by the development of the costocentral joint owing to the occurrence of liquefaction in the cartilage connecting the two.* In the

* James Whillis, *J. Anat. Lond.*, 74, 1940.

cervical vertebrae (fig. 115) the transverse process forms the posterior boundary of the foramen transversarium, while the costal process, corresponding to the head and neck of the rib, remains in continuity with the body of the vertebra, and forms the anterior and lateral boundaries of this foramen. The distal portions of the primitive costal arches remain undeveloped; occasionally, however, the costal processes of the seventh cervical vertebra undergo greater development, and by the formation of costovertebral joints are separated off as cervical ribs. In the *lumbar vertebrae* the distal portions of the primitive costal arches fail; the proximal portions fuse with the transverse processes to form the transverse process of descriptive anatomy.

FIG. 115.—Diagrams showing the portions of the adult vertebrae derived respectively from the centra (dark blue), neural arches (pink), and costal processes (light blue) of the embryonic vertebrae.



Occasionally a pair of movable ribs is developed in connexion with the first lumbar vertebra. In the *sacral vertebrae* costal processes are developed only in connexion with the upper three or four vertebrae; the processes of adjacent segments fuse with one another to form the anterior portion of the lateral part of the sacrum on each side. The *coccygeal vertebrae* are devoid of costal processes.

The sternum.—The ventral ends of the upper nine ribs become united to one another by a longitudinal bar termed the *sternal plate*, and the two sternal plates fuse in the median plane. Incomplete union of these two sternal plates may result in the presence of a foramen in the adult bone (p. 255). Both ribs and sternal plates consist at first of condensed mesenchyme, which later becomes chondrified. The eighth and ninth ribs lose their connexion with the sternum, and the portion so freed becomes the xiphoid process. This process of separation may be arrested too soon, and in this event the number of true ribs is increased to eight, or it may be carried too far and so cause a reduction in the number from seven to six. The ossification of the ribs and sternum is described on pp. 256 and 261.

The skull.—The bones of the cranium are developed in the mesenchyme which invests the cerebral vesicles, but, before the osseous stage is reached, the skull passes through, firstly, a blastemal or membranous stage, and, secondly, a cartilaginous stage. The chondrocranium, which is formed in the second stage, is incomplete, and most of the cranial vault and portions of the base are not preformed in cartilage.

The membranous or blastemal skull.—At the end of the first month of intrauterine life and the beginning of the second, the mesenchyme which surrounds the developing brain increases in thickness and forms localised masses which represent the earliest distinguishable elements of the skeleton of the head. These masses first become evident in the occipital region, where they form the *occipital plate*, which outlines the basilar part of the occipital bone. Two extensions grow laterally from each side of the plate, and their lateral extremities fuse with each other to complete a foramen around the hypoglossal nerve. At the same time the mesenchymal condensation extends forwards, dorsal to the pharynx, and reaches the rudiment of the hypophysis, thus outlining the clivus and dorsum sellæ of the sphenoid bone. Early in the second month it surrounds the duct of the hypophysis and extends between the right and left halves of the nasal cavity, where it forms the basis of the ethmoid bone and nasal septum.

The notochord traverses the occipital plate obliquely from its dorsal to its ventral surface and comes into intimate relation with the epithelium of the dorsal wall of the pharynx, with which it is for a time directly connected. It re-enters the base of the membranous skull and runs forward to terminate caudal to the hypophysis (fig. 116).

About the fifth week the two auditory vesicles (p. 150) become enclosed in mesenchymal capsules, each of which is soon differentiated into a dorsolateral part enveloping the semicircular ducts, and a ventrimedial part surrounding the cochlea; at the upper boundary between these two parts the facial nerve lies in a deep groove. The auditory capsules fuse with the lateral processes of the occipital plate, leaving a wide gap through which the internal jugular vein, and the glosso-pharyngeal, vagus and accessory nerves are transmitted.

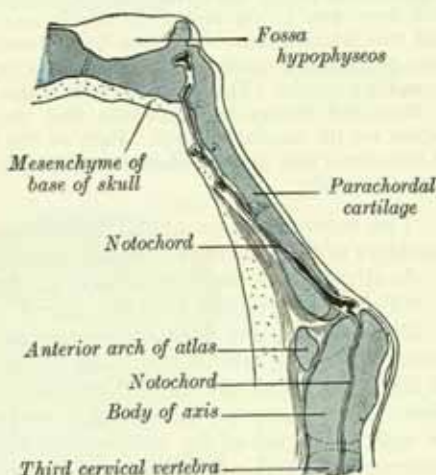
At this stage the mesenchyme which surrounds the hypophyseal duct and forms the rudiment of the post-sphenoid part of the body of the sphenoid bone sends out a wing-like process on each side—the future greater wing. More anteriorly processes extend laterally and indicate the sites of the lesser wings of the sphenoid bone, while condensations occur on each side of the nasal cavity and blend above with the mesenchymal septum.

The first indications of the vault of the skull are seen about the thirtieth day, and consist of plates of mesenchyme which appear at the sides of the head and gradually extend into the upper wall where they blend with one another; they also blend with the parts at the base of the cranium.

The chondrocranium.—In the shark and dogfish the mesenchymal cranium undergoes complete chondrification and forms the cartilaginous skull or chondrocranium of these animals.

In mammals the process of chondrification is limited to the base of the skull, including a region dorsal to the foramen magnum. Chondrification takes place primarily in three regions: (a) posterior, in relation to the notochord; (b) intermediate, in relation to the hypophysis; and (c) anterior, between the orbits and the nasal cavity. These parts may be named *chordal*, *hypophyseal*, and *interorbitonasal*. The chordal part is developed from the mesenchyme related to the cranial end of the notochord, and in its caudal part it exhibits traces of four primitive segments separated from one another by the roots of the hypoglossal nerve. It is uncertain what the hypophyseal part represents; when ossified it forms the post-sphenoid. The interorbitonasal part is, perhaps, identical with the trabeculæ cranii of most lower vertebrates.

FIG. 116.—A sagittal section through the cephalic end of the notochord. (Keibel.)



* In man chondrification of the skull begins in the second month of intrauterine life, and the first cartilaginous nuclei appear in the occipital plate, one on each side of the notochord. About the thirty-sixth day these two nuclei fuse anteriorly on the dorsal surface of the notochord, and later they fuse posteriorly on its ventral surface. Thus the notochord lies dorsal to the caudal part of the cartilaginous occipital plate, then traverses the plate and lies ventral to it, and finally enters the plate again to end in the dorsal surface of the post-sphenoid cartilage (fig. 116).

The posterior part of the sphenoid cartilage chondrifies from two centres, one on each side of the developing hypophysis; these unite first behind the duct of the hypophysis and then in front of it, and in this way the *craniopharyngeal canal*, which transmits the hypophyseal diverticulum, is formed; this canal is usually obliterated at the third month (p. 186).

The auditory capsule, the presphenoid, the roots of the greater wings, the lesser wings and, finally, the nasal capsule in turn become chondrified. The last-named is well developed by the end of the third month. It consists of a median part (or septum) and two lateral parts. The free lower border of the lateral part becomes incurved to form the inferior nasal concha, which ossifies at the fifth month and becomes detached from the capsule. The posterior part of the lateral part of the capsule becomes ossified to form the ethmoidal labyrinth, and the middle and superior conchæ appear as ridges on its medial surface. Part of the rest of the capsule remains cartilaginous as the septal and alar cartilages of the nose and part is replaced by membrane bones (vomer, nasal).

The ventral surface of the chondrocranium is indirectly connected with the cartilages of the visceral arches, the fate of which is described below.

As already indicated the bones of the base of the skull are preformed in cartilage, in which the occipital (basilar, lateral and squamous parts), the petrous part of the temporal, the body, lesser wings and roots of the greater wings of the sphenoid, and the ethmoid bone are laid down. The bones of the vault of the skull, on the other hand, are ossified in membrane, and are termed *dermal* or *covering bones*. They comprise the frontal bone (including its orbital parts), the parietals, the squamous part of the temporal and the upper part of the squama occipitalis (interparietal part). *It will be seen, therefore, that with the exception of the orbital parts of the frontal bone and the lateral part of each greater wing, the whole of the base of the skull is preformed in cartilage, while the whole of the vault, including the supra-occipital part of the occipital bone, ossifies directly in membrane.*

The stage of ossification commences before the chondrocranium has yet reached the height of its development. As the process of ossification extends, the chondrocranium, after reaching its maximum extent, becomes rapidly reduced, but portions of it still persist at birth, and some are found in the adult skull. At birth the cartilage of the chondrocranium is present: (1) in the cartilages of the alæ and septum of the nose; (2) in the sphenoid bone (p. 319); (3) in the sphenoccipital (p. 452) and the petro-occipital joints (p. 452); and (4) in the foramen lacerum.

The ossification of the bones of the skull is given with the description of the individual bones.

The development of the appendicular skeleton is dealt with on p. 120.

THE BRANCHIAL APPARATUS

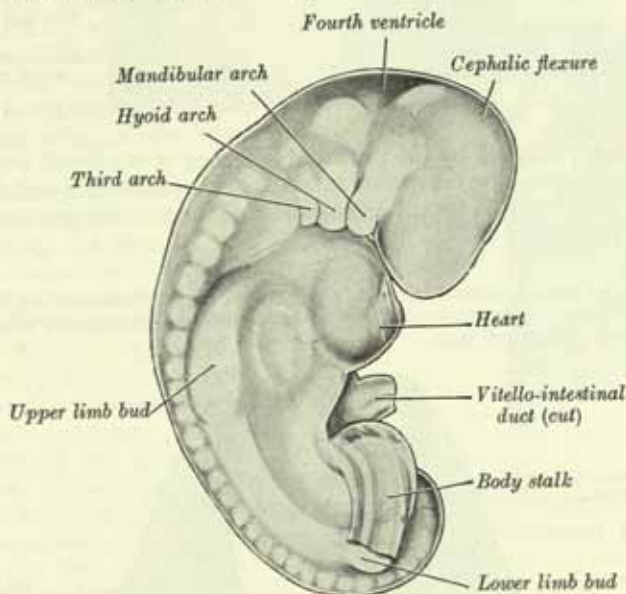
After the formation of the head-fold the stomodæum, or primitive mouth, is bounded on its headward side by the forward projection of the fore-brain and on its caudal side by the pericardium (fig. 169). The lower part of the face and the whole of the neck, which subsequently intervene between the mouth and the pericardium, owe their formation to the development of a series of six **visceral arches**, which appear on the lateral aspect of the head in the region of the hind-brain (fig. 117). The first of these arches corresponds to the lower jaw of the fish, the second to the operculum or gill cover, and the remaining four to the branchial or gill arches. The mesenchyme of the head region (p. 76) at first forms a thin sheet intervening between the ectoderm and the entoderm but, as growth proceeds, it proli-

* For a detailed description the reader is referred to the work of Professor E. Fawcett, published in the *Journal of Anatomy and Physiology*, volumes xlv, li, and lii, and in the *Proceedings of the Anatomical Society of Great Britain and Ireland*, 1916.

ferates and gives rise to a series of somewhat cylindrical processes which constitute the arches. At first the arches form rounded ridge-like projections in the overlying ectoderm and corresponding projections in the entodermal floor of the pharynx. These ridges are separated from one another by a series of furrows, where the surface ectoderm and the pharyngeal entoderm come into direct contact with each other. The ectodermal furrows are termed the **branchial** or **visceral clefts** and the entodermal furrows the **pharyngeal pouches**. At this stage the pharynx, which is wide at its cephalic end but rapidly narrows as it is traced caudally, is very shallow dorsiventrally. It possesses a wide roof and a wide floor, which meet on each side, so that there is no true lateral wall (fig. 119).

The early appearance of the arches and their intimate relationship to the mouth and to the heart and pericardium, not only in man but in the embryos of all the vertebrata, are explained by their functional significance in the lower vertebrates.

FIG. 117.—A 26½ days macaque embryo, showing an early stage in the development of the branchial arches and the limb buds. (C. H. Heuser and G. L. Streeter, *Contribs. to Embryol.*, 29, 1941.) ($\times 12$.)

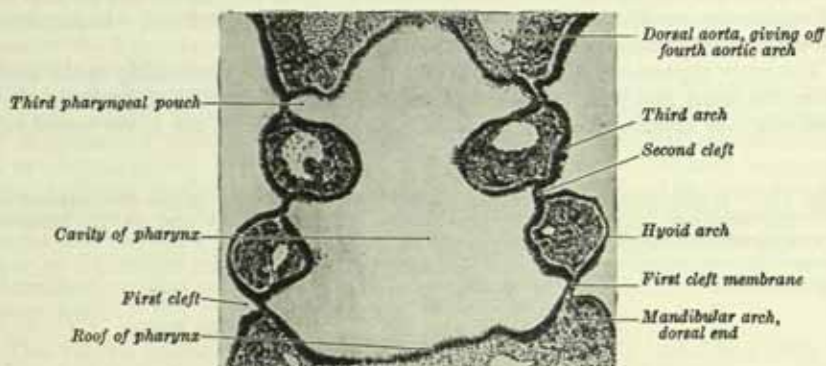


They provide for water-breathing animals a convenient and efficient respiratory apparatus. From the arterial, headward end of the heart there emerge two ventral aortae, which pass headwards on the ventral aspect of the pharynx and send branches dorsally, one entering the substance of each arch. In the substance of the arches these vessels break down into a thin-walled capillary plexus from which corresponding vessels emerge and run dorsally to join the dorsal aortae—two large vessels situated on the dorsal aspect of the pharynx. The branchial clefts in these animals break down and a series of gill slits develop which communicate between the exterior and the inside of the pharynx. Periodically the oxygen-bearing water is taken into the pharynx through the mouth and expelled through the gill slits. In its passage it bathes the entodermal surfaces of the branchial arches, which are specially adapted to expose to it a large area filled with capillaries. The blood gives up its carbon dioxide and absorbs fresh oxygen in its place, and this oxygenated blood is carried into the dorsal aortae to be distributed all over the body. The periodic intake of water for this purpose is the equivalent of inspiration in an air-breathing vertebrate, and the process provides a respiratory mechanism in which water and not air is the oxygen carrier.

The *first* or *mandibular arch* grows ventrally and medially in the floor of the pharynx until it meets the corresponding arch of the opposite side in the median plane. It comes to lie, therefore, between the primitive mouth and the pericardium

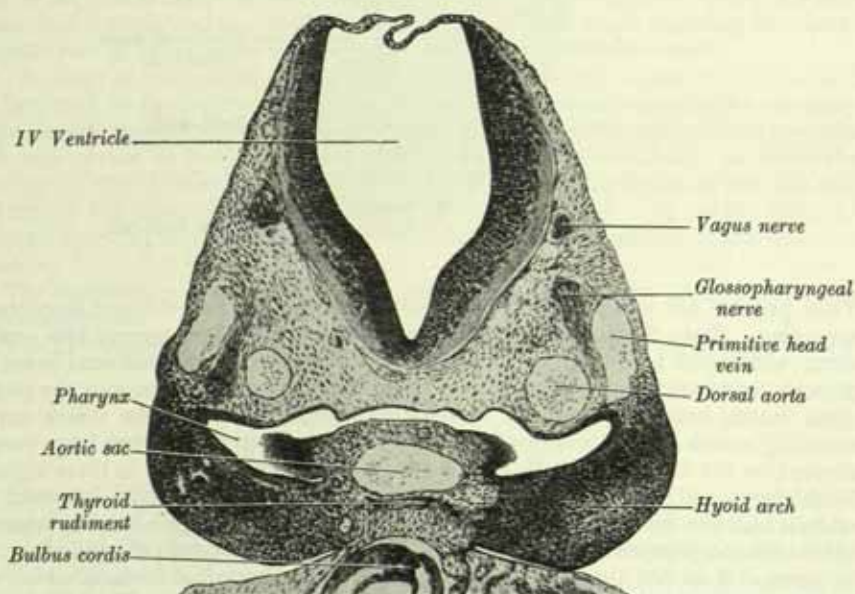
(fig. 241). The *second* or *hyoid arch* grows ventrally on its caudal side, and separated from it on the outside by the first cleft. It, too, ultimately reaches the median plane and fuses with its fellow. The succeeding *third* and *fourth arches*, but especially the fourth, do not attain any great degree of prominence, and are for the most part sunk

FIG. 118.—A transverse section through the pharynx of a human embryo. C.R. length = 2 mm. (E. H. Norris, *Contr Embryol.*, Carneg Instn., 27, 1938.) ($\times 50$.)



in a depression produced by the caudal overlapping of the hyoid arch. The *fifth* and *sixth arches* cannot be recognised on the outside of the neck and their presence can only be demonstrated by the arrangement of the mesenchyme and the projections in the pharyngeal wall.

FIG. 119.—Coronal section through the head of a mole embryo, 4.5 mm. long. The section passes through the hind-brain, the pharynx, the hyoid and a part of the third visceral arch.



It should be observed that each arch consists of an ectodermal covering, a mesodermal core, and an entodermal covering (fig. 118). The mesodermal core gives rise to a *skeletal element*, which subsequently chondrifies in whole or in part and, if complete, extends dorsally until it comes into contact with the membranous capsule of the hind-brain. Most of the remainder of the mesodermal core later gives rise to striated *muscle*, which may migrate and lose all attachment to the primitive skeletal element of the arch. The history of these muscle masses can, however, easily be

traced by reference to their nerve-supply. The dorsal end of each arch, as has already been pointed out, lies close to the ventrolateral aspect of the hind-brain (fig. 119) and the motor nerves which arise from this part of the brain pass directly into the arches. The innervation of the muscle masses once established will persist, no matter how far the muscle may migrate from the site of its development. The mandibular division of the trigeminal nerve supplies the mandibular arch; the facial nerve, the hyoid arch; the glossopharyngeal, the third arch; the vagus and accessory, the remaining arches. The recurrent laryngeal is probably the nerve to the sixth arch and the superior laryngeal that to the fourth, but the nerve of the fifth arch—which is always difficult to identify and leaves few traces of its existence—is uncertain.

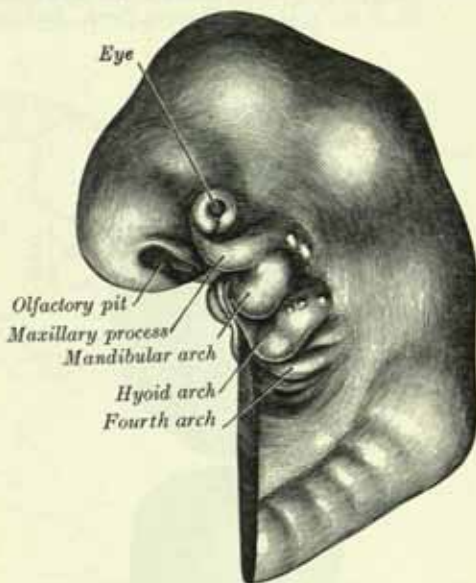
The branchial apparatus plays an important part in the formation of the face and neck, mouth, pharynx and larynx, but before a detailed survey is made of the history of the arches it is convenient at this stage to describe the steps which lead to the formation of the face and the demarcation of the nasal cavity.

Development of the face, nose and palate.—While the mandibular arch is invading the floor of the pharynx, the mesenchyme between the floor of the fore-brain and the epithelial roof of the mouth becomes thicker and deeper and, together with its covering ectoderm, constitutes the *frontonasal process*. During the fifth week a thickened patch of ectoderm appears on the ventrolateral surface of the frontonasal process on each side and divides it into a *median* and right and left *lateral nasal processes*. The placodes, which at first are widely separated from each other, soon become depressed to form the *olfactory pits* (fig. 120) and their lateral and medial margins become raised to constitute the lateral and medial *nasal folds*. The lateral fold is the more prominent (fig. 120) but the medial fold projects caudally beyond it and the mesenchyme of this extension into the stomodæal roof proliferates to form the *globular (premaxillary) process*.

While these changes are in progress a somewhat triangular process grows ventrally from the cephalic side of the dorsal end of the mandibular arch. It is termed the *maxillary process* and, like the frontonasal process, it consists of a core of mesenchyme covered with ectoderm. The maxillary process grows ventrally to fuse with the lateral nasal process, from which it is separated at first by a groove, termed the *naso-optic furrow** (fig. 121 C).

The opposed margins of the lateral nasal and maxillary processes fuse with each other to establish continuity between the side of the nose and the adjoining part of the cheek (fig. 121 D). The ectoderm along the line of fusion does not disappear entirely, for its deeper part gives rise to a solid, cellular rod, which sinks beneath the surface. Its caudal, free end secondarily establishes a connexion with the caudal part of the lateral wall of the nasal cavity while its cranial end later acquires connexions with the conjunctival sac. Later, this rod becomes canalised to form the *nasolacrimal duct*. The blunted apex of the triangular maxillary process extends beyond the lateral nasal fold and crosses the caudal

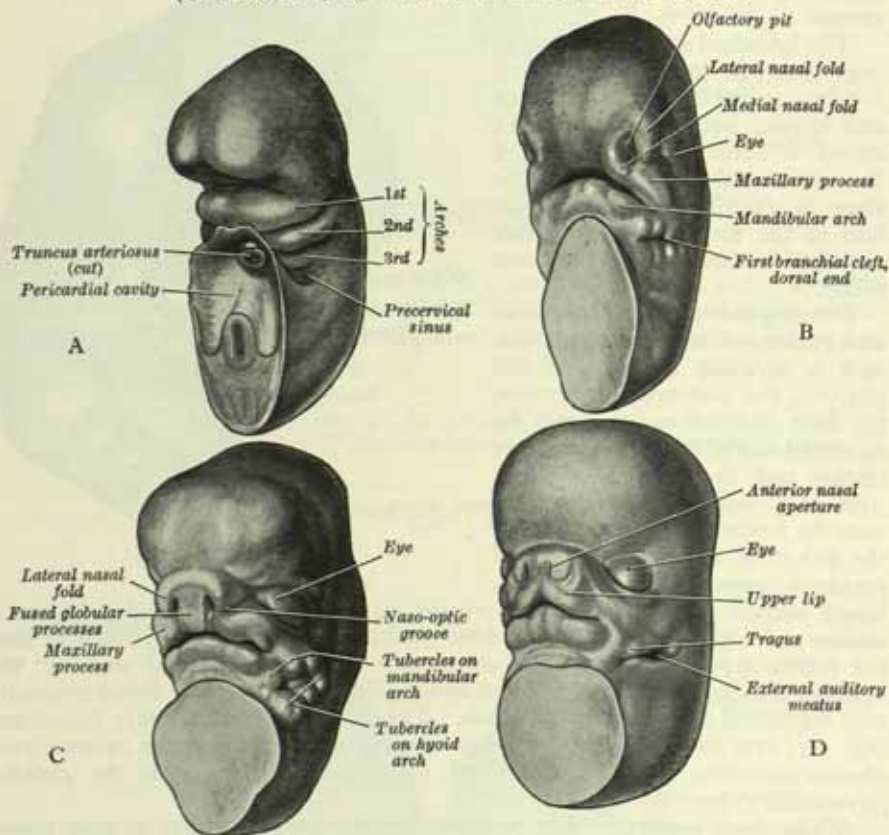
FIG. 120.—The head-end of a human embryo, about the fifth week. Lateral aspect. (From a model by Peter.)



* This account follows the description given by J. E. Frazer (*Manual of Embryology*, Baillière, Tindall and Cox, London, 1931) and, although substantially the same, differs in certain details from the more recent description given by G. L. Streeter (*Contr. Embryol.*, Carneg. Instn., 32, 1948).

(lower) end of the olfactory pit to meet and fuse with the globular (premaxillary) process. In this way the lower part of the olfactory pit loses its direct opening on the surface, while the upper part of the opening of the pit can now be recognised as the *primitive anterior naris*. The growth of the surrounding mesenchyme permits the olfactory pit to deepen to form the *primitive nasal cavity* and its epithelial wall, in its dorsi-caudal part, retains continuity with the epithelium of the stomodæal roof. As growth proceeds, this continuity becomes stretched and thinned out, forming the *bucconasal membrane*, which disappears at an early date. Thereafter the primitive nasal cavity opens on to the roof of the forepart of the stomodæum through the *primitive posterior naris*.

FIG. 121.—Four stages in the development of the human face and auricle.
(G. L. Streeter, *Contr. Embryol., Carnegie Instn.*, 14, 1922.)



A. C.R. length, 6 mm. ($\times \delta$. 11).

B. C.R. length, 12 mm. ($\times \delta$. 7.5).

C. C.R. length, 14 mm. ($\times \delta$. 7.5).

D. C.R. length, 18 mm. ($\times \delta$. 6).

At the same time a new upper boundary is formed for the oral fissure and it consists of the fused globular (premaxillary) and maxillary processes. It is really the upper lip, although it has not yet been freed from the deeper tissues which form the maxillary alveolus (fig. 124). At the same time the primitive nasal cavity acquires a floor formed by the fused lateral nasal and maxillary processes. At this stage the anterior nares are completely defined, but they are still widely separated from each other by an area which soon becomes relatively narrower, owing to the fusion of the mesenchymal cores of the globular processes. According to some investigators * the mesenchyme of the maxillary processes invades the fused globular (premaxillary) processes, the mesenchyme of which becomes buried and later gives origin to bone—the os incisivum or premaxilla. The maxillary mesenchyme is believed to make a substantial contribution to the formation of the philtrum of the upper lip and to account for its innervation by the maxillary nerve. Others, however, maintain that

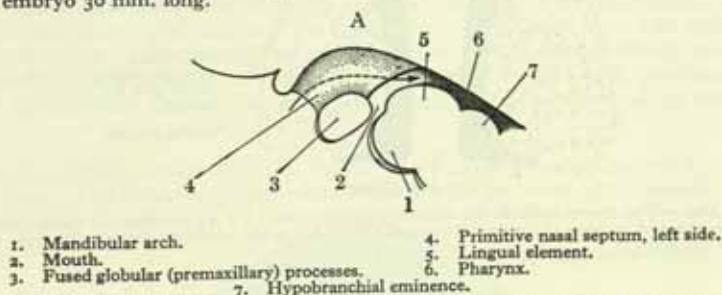
* J. D. Boyd, *J. Anat., Lond.*, 67, 1933, and J. E. Frazer, *loc. cit.*

the philtrum is formed wholly by the globular processes and that distribution of the sensory nerves does not provide a reliable guide to the migration of the maxillary mesenchyme.*

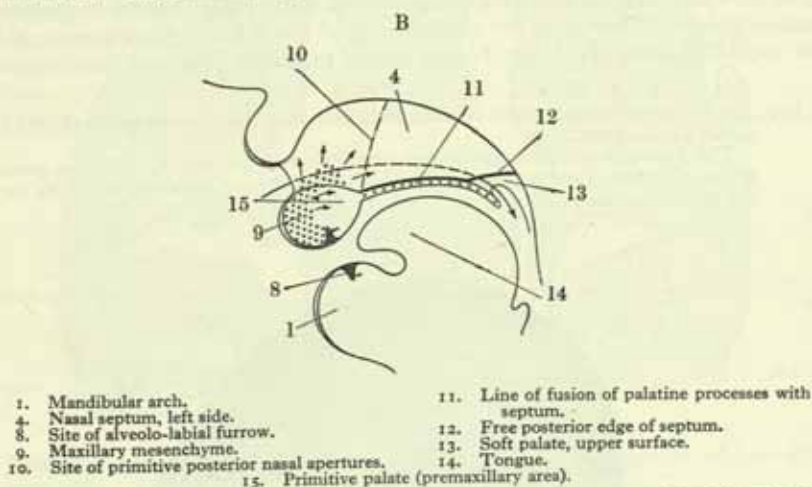
After the formation of the primitive nasal cavities the anterior portion of the roof of the mouth constitutes the *primitive palate* (fig. 124). It is formed by the fused globular (premaxillary) and maxillary processes and is continuous above with the broad median partition which separates the cavities and constitutes the *primitive nasal septum*.

As the head grows in size the mesenchyme which intervenes between the floor of the fore-brain and the mouth increases greatly in amount and the nasal fossæ

FIG. 122.—Diagrammatic parasagittal sections through the regions of the developing nasal cavity and mouth: (A) in an embryo 14.5 mm. long; and (B) in an embryo 30 mm. long.



The arrow passes through the right primitive nasal cavity and appears posteriorly in the mouth by emerging through the primitive posterior naris. The cavity of the mouth communicates freely with the nasal cavities. Compare with fig. 125.



The long arrow passes through the right half of the nasal cavity and appears posteriorly through the definitive posterior naris, lying above the developing soft palate.

The maxillary mesenchyme, shown by cross-hatching, has buried the premaxillary area and is extending in the directions indicated by the small arrows.

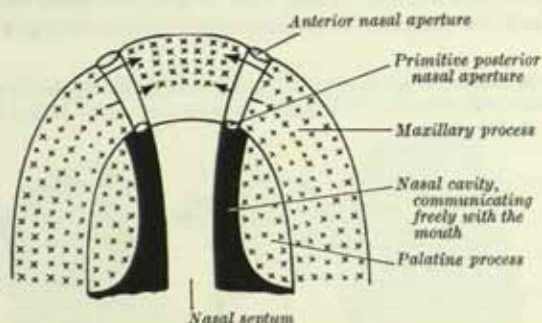
The palatine processes have fused with one another and with the caudal border of the nasal septum, intervening between the tongue and the nasal cavity.

deepen (i.e. extend towards the fore-brain). At the same time they extend backwards from the primitive posterior nasal apertures as two narrow but deep grooves in the roof of the mouth (fig. 123), separated by a broad partition which increases in depth as the fossæ deepen. This partition is the *nasal septum*, and it is continuous in front with the primitive nasal septum. Its broad caudal surface lies free in the roof of the mouth and is at first in contact with the dorsum of the developing tongue (fig. 125). The nasal cavity is thus subdivided into right and left parts, which communicate freely with the cavity of the mouth except anteriorly, where the floor is formed by the primitive palate.

* W. His, *Anatomie menschlicher Embryonen*, Leipzig, 1885. A. Keith, *Human Embryology and Morphology*, London, 1933. G. Pollitzer, *Z. ges. Anat.*, 1. *Z. Anat. Entw.-Gesch.*, 116, 1952. T. S. King, *J. Anat.*, Lond., 99, 1954.

In the sixth week the inner surface of the maxillary process gives rise to a *palatine process*, which projects caudally from it and lies in contact with the side of the tongue (fig. 125). At this time the roof of the mouth projects forwards beyond its caudal boundary (fig. 122 A), and the developing tip of the tongue lies above and behind the primitive palate. More dorsally a coronal section through

FIG. 123.—A diagram to represent a transverse section through the developing face at the level of the anterior nares in an embryo of the seventh week.

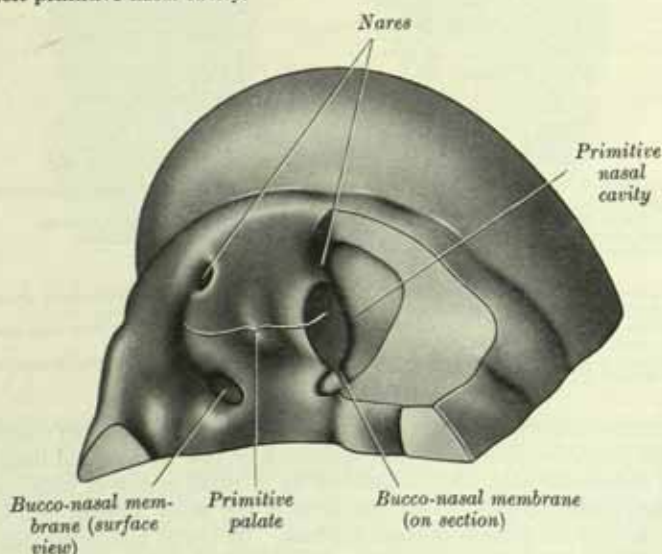


Note.—The arrows indicate the maxillary mesenchyme (x x x) invading the fused globular processes and burying the premaxillary area which forms the primitive palate. Compare with figs. 122 and 125.

the body of the tongue shows the palatine processes in contact with its lateral aspects (fig. 125). As growth proceeds the mandibular region and the tongue are carried forwards and the tip of the tongue of necessity passes caudal to (below) the primitive palate. Thereafter the ventral ends of the palatine processes are able to grow medially, along the lower border of the primitive posterior nasal apertures

FIG. 124.—The primitive palate of a human embryo in the seventh week. (From a model by K. Peter.)

The figure shows the anterior part of the roof of the mouth, and large parts of the left lateral nasal and maxillary processes have been removed to expose the left primitive nasal cavity.



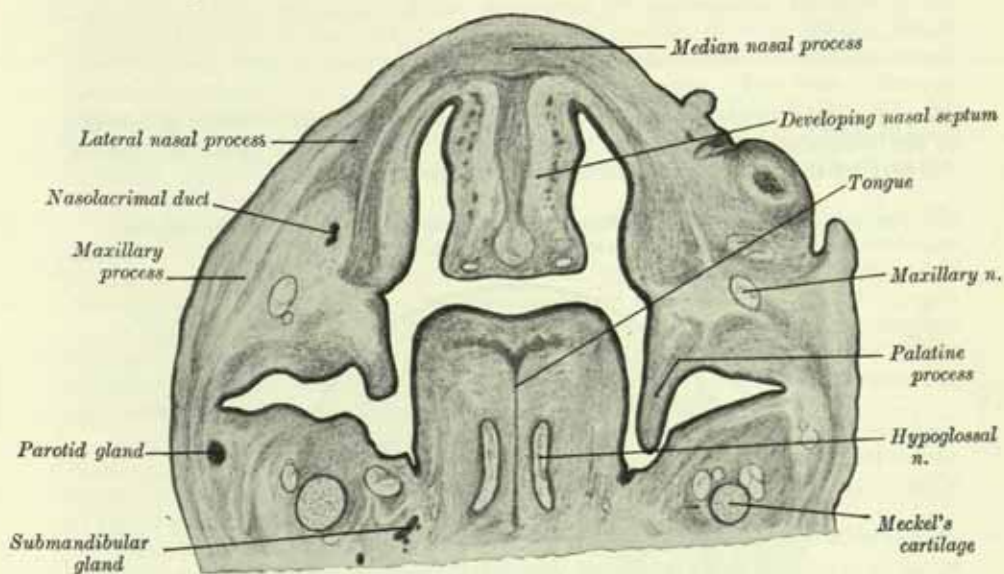
until they meet and fuse with each other in the median plane and with the free lower border of the nasal septum above (fig. 127). This process of fusion now extends dorsally in the interval between the septum and the dorsum of the tongue and, as it does so, the nasal cavities lengthen and the posterior nasal apertures are carried dorsally until they reach their definitive position at the junction of the ventral three-fourths with the dorsal fourth of the caudal edge of the septum. The

dorsal fourth persists as the free posterior edge of the septum in the adult. At a slightly later stage the extreme dorsal parts of the palatine processes meet and fuse with each other to form the soft palate (fig. 122 B). There is later an upgrowth of third arch mesoderm into the palate and around the caudal margin of the auditory tube. The line of this migration is marked in the adult by the palatopharyngeal arch.*

On each side of the nasal septum, at its caudal and ventral part, the ectoderm is invaginated to form a diverticulum which extends dorsally and headwards into the nasal septum. These diverticula form the *vomeronasal organs*, which open close to the junctions of the premaxillae and maxillae; they are always rudimentary in man.

Congenital malformations involving arrest of development during the formation of the face and palate are not uncommon. In the simplest form, the maxillary process on one side fails to fuse completely with the globular (premaxillary) process and a fissure is present between the philtrum and the lateral part of the upper lip. The condition is known as *hare-lip*. A similar type of malformation, but of comparatively rare occurrence, results from the failure of the maxillary process to fuse with the lateral nasal process. In this case the nasolacrimal duct forms an open furrow along the side of

FIG. 125.—Oblique coronal section through the head of a human embryo 23 mm. long. The nasal fossae communicate freely with the cavity of the mouth.



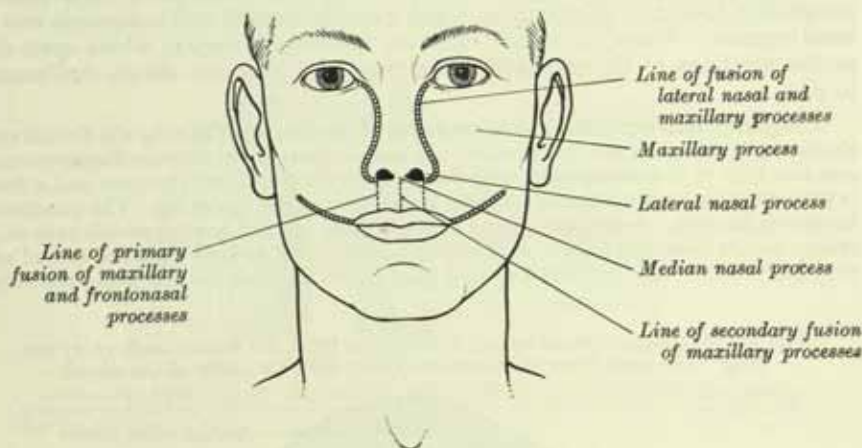
the nose, and the condition is usually associated with the presence of hare-lip on the same side.

The palatine processes may fail to fuse with each other and with the nasal septum, giving rise to the condition of *cleft palate*. In its grossest form no fusion occurs in the roof of the mouth. The edges of the palatine processes are separated by a wide median fissure in which the free lower border of the nasal septum can be seen. Anteriorly the premaxillary portion of the palate is separated from the palatine processes by a fissure on each side, and these fissures are continuous in front with the clefts in a double hare-lip. In such cases the fused globular processes exist as a separate entity, continuous above and behind with the nasal septum. The floor of the nasal fossa is deficient throughout its whole extent and the posterior nasal apertures have never been defined. All varieties of milder degrees of cleft palate have been recorded. In the commonest type the condition is unilateral, i.e. one palatine process has fused with the primitive palate and with the nasal septum, but the other has failed to do so and the extent of the cleft is variable. The mildest degree results in a bifid uvula only, or in a cleft which is limited to the soft palate.

Such arrests of development are indicative of nutritional disturbances in the embryo during the second and third months of development, and the grosser varieties are usually associated with malformations affecting other parts of the body.

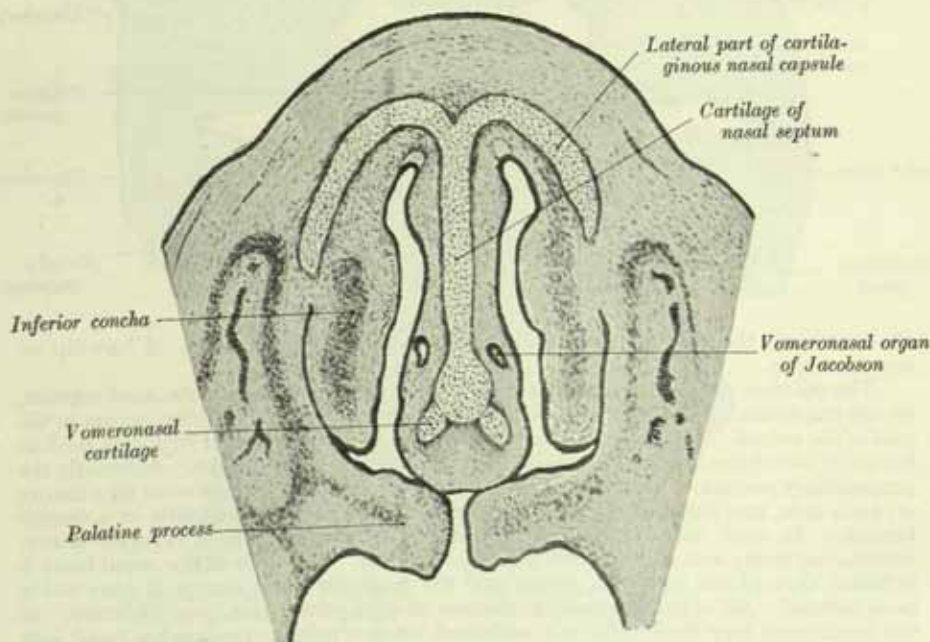
The subsequent history of the visceral arches.—The visceral arches contribute extensively to the formation of the face, the neck, the mouth, the pharynx and the larynx; the visceral clefts, with the exception of the first, which forms the

FIG. 126.—A diagram to show the parts of the adult face which are derived from the lateral and median nasal processes, the maxillary process and the mandibular arch.



external auditory meatus, disappear entirely; the pharyngeal pouches give origin to the tympanic cavity and the auditory tube, the tonsillar pits, the thymus, the parathyroids and to parts of the thyroid gland.

FIG. 127.—A coronal section through the nasal cavity of a human embryo 28 mm. long. (Kollmann.)



Ectodermal derivatives.—The ectoderm over the mandibular arch is responsible for the formation of that part of the skin of the face which covers the mandible (fig. 126) and, in addition, it takes part in the formation of the tragus of the auricle (p. 152). The ectoderm on the cephalic aspect of the arch thickens along a curved line which is later converted into the *alveolo-labial sulcus*. The epithelial proliferation invades the underlying mesenchyme and subsequently breaks down, so as

to separate the lower lip from the developing gum. Before it does so, however, it gives rise on its inner surface to an epithelial lamina (fig. 1136) from which the enamel of the teeth is derived at a later stage (p. 1368).

The first cleft becomes obliterated in its ventral portion, but its dorsal end deepens and forms the epithelial lining of the external auditory meatus.

At the dorsal ends of the first, second and third clefts thickened patches of ectoderm, termed *epibranchial placodes*, appear. These are intimately related to the underlying ganglia of the seventh, ninth and tenth cranial nerves.

At the end of the fifth week the third and fourth arches lie at the bottom of a small depression, which is termed the *precervical sinus*. On the cephalic side the sinus is bounded by the hyoid arch; dorsally, it is limited by a ridge produced by downgrowths from the occipital myotomes and by pre-muscle tissue which subsequently forms the sternomastoid; and caudally, by a smaller ridge, termed the *epipericardial ridge*, which separates the sinus from the pericardium and curves headwards, medial to the ventral ends of the arches, to reach the mandibular arch.* The muscle cells which migrate from the occipital myotomes to reach the tongue follow the epipericardial ridge and carry the hypoglossal nerve with them. Recent investigations have not substantiated the classical description that the hyoid arch gradually grows caudally to fuse with the pericardium and enclose the caudal arches into a cervical vesicle, thus excluding them from any share in the formation of the surface of the neck. The precervical sinus is reduced by approximation of its walls from within outwards. At the same time the epibranchial placodes at the dorsal ends of the second and fourth clefts sink inwards to form vesicles which ultimately lose their connexion with the surface ectoderm and become intimately associated with the ninth and tenth cranial nerve ganglia. The vesicle derived from the placode on the fourth cleft is also closely associated for a time with the thymus and parathyroid rudiments arising from the third entodermal pharyngeal pouch (p. 185).† There is, however, no evidence that the thymus in man receives any contribution from this vesicle.

Experimental studies in lower vertebrates provide strong evidence that the ganglia of the seventh, ninth and tenth cranial nerves receive contributions from the overlying placodes or are dependent upon the associated placode for their full development. In man the placodal vesicles formed in association with the ganglia of the ninth and tenth cranial nerves are believed normally to undergo complete regression and disappear. Persistence of these placodal vesicles may give rise to branchial cysts lined by stratified squamous epithelium and lying along the surface of the carotid sheath deep to the sternocleidomastoid muscle.‡

It is claimed that branchial cysts lined by columnar epithelium may arise from persisting remnants of the entodermal pharyngeal pouches, whilst branchial fistulae result from a persistence of the lower end of the second branchial cleft or possibly of the precervical sinus.

Mesodermal derivatives.—The mesoderm of the visceral arches is still pluripotent and this character expresses itself in a number of ways. (1) An endothelial tube, termed an *aortic arch*, is constituted in each arch and connects the aortic sac on the ventral aspect of the pharynx (p. 168) with the dorsal aorta on its dorsal aspect. (2) Some of the mesodermal cells condense to form a *skeletal element* in each arch: typically this forms a bar of cartilage connected to the caudal aspect of the chondrocranium at its dorsal end and meeting its fellow of the opposite side at its ventral end. (3) Others of the mesodermal cells differentiate to form a unit of *voluntary muscle*. In addition the mesoderm of each arch is invaded, typically, by two nerves derived from the hind-brain. Of these one runs along the cephalic border of the arch and is therefore 'post-trematic' (i.e. immediately caudal to a cleft) in position, and the other along the caudal border of the arch and is 'pre-trematic' in position. In the human embryo this double innervation can be determined only in the first arch. Further the mesoderm of the arches contributes to the formation of the fibro-areolar and other connective tissues of the lower part of the face, the tongue and the neck, while that of the third arch gives origin to the carotid body.§

* J. Ernest Frazer, *J. Anat.*, Lond. **61**, 1926.

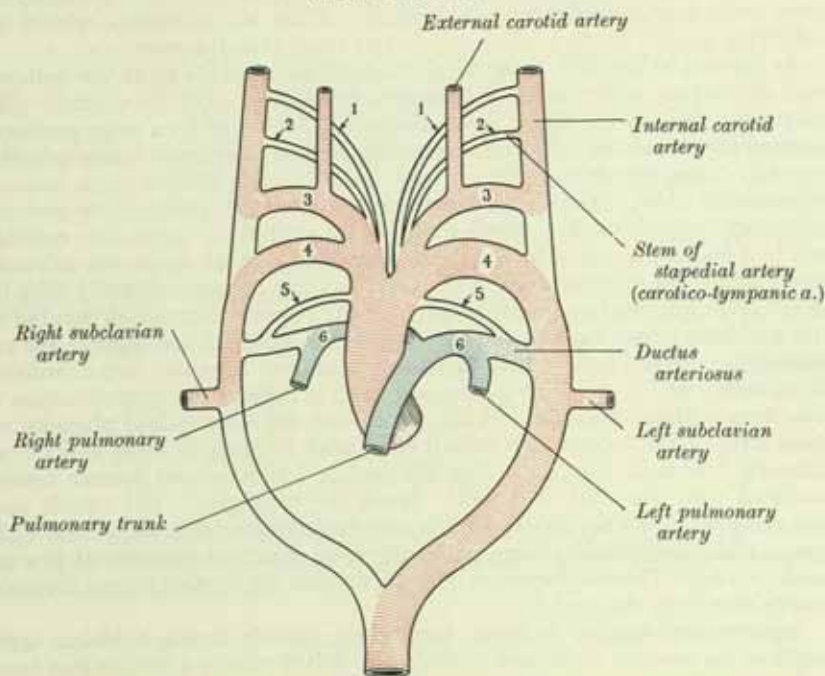
† F. D. Garrett, *Anat. Rec.*, **100**, 1948.

‡ C. P. Wilson, *Annals. Roy. Coll. Surg. Eng.*, **17**, 1955.

§ J. D. Boyd, *Contr. Embryol.*, Carneg. Instn., **26** 1937.

Aortic arches.—The first and second aortic arches of each side disappear, but the third aortic arch persists as the lower, or proximal, portion of the internal carotid artery and the whole of the common carotid (fig. 128). The fourth aortic

Fig. 128.—A scheme of the aortic arches and their transformations.
(After Congdon.)



The vessels left uncoloured disappear entirely in the course of normal development and cannot be identified after birth.

arch of the right side forms the proximal part of the right subclavian artery, but on the left side it becomes the part of the arch of the aorta which lies between the origins of the left common carotid artery and the left subclavian. The fifth aortic arch disappears entirely, but the sixth on each side gives off a branch to the developing lung-bud. When the truncus arteriosus becomes divided into the pulmonary trunk and the ascending aorta the sixth arches remain in connexion with the former. On the right side the dorsal portion of the sixth aortic arch disappears, but on the left side it forms the *ductus arteriosus*, which functions during intrauterine life and becomes converted into the fibrous *ligamentum arteriosum* after birth.

Skeletal elements.—The skeletal element of the first arch is termed *Meckel's cartilage*. It extends from the basal aspect of the developing auditory capsule into the mandibular arch, and, ventrally, it turns upwards in contact with its fellow of the opposite side. The dorsal end of the cartilage becomes separated and forms the *incus* and the *malleus*, including its anterior process. The intermediate portion is represented in the adult by the *anterior ligament of the malleus* and *sphenomandibular ligament*. The succeeding portion of the cartilage partly disappears and partly is incorporated in the mandible, which develops as a membrane bone on its lateral aspect. The ventral ends of the two cartilages persist in the symphysis menti for a time, and are probably responsible for the formation of the *mental ossicles* (p. 308).

The cartilage of the second arch also extends from the auditory capsule to the mid-ventral line. Its dorsal end becomes separated and enclosed in the tympanic cavity, forming the *stapes*. Thereafter the cartilage is represented in the adult by the *styloid process*, the *stylohyoid ligament*, the *lesser cornu* and possibly the *upper part of the body of the hyoid bone* (fig. 129).

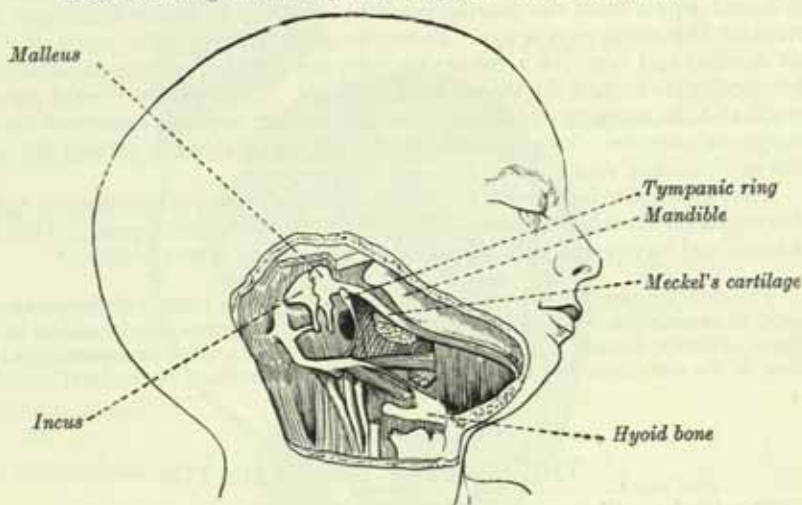
Chondrification does not occur in the dorsal portions of the third, fourth, fifth and sixth arches. The cartilage in the ventral portion of the third arch persists as

the *greater cornu of the hyoid bone* and the *lower part or all of its body*. According to Frazer, the body of the hyoid bone chondrifies in the base of the hypobranchial eminence and belongs to the third arch only, its connexion with the skeletal element of the second arch being acquired secondarily.

There is considerable difference of opinion concerning the fate of the skeletal elements of the fourth, fifth and sixth arches. Frazer believes the thyroid cartilage represents the fourth arch cartilage only, others consider it to be composed of the fourth and fifth arch cartilages. The epiglottis is developed in the substance of the hypobranchial eminence but probably does not represent a branchial arch cartilage. The cricoid and arytenoids are formed in the substance of the sixth arch. Some authorities regard the cricoid as a modified tracheal ring which has become included in the larynx, Frazer refers it to the sixth arch but others maintain that it is derived from the skeletal element of the fifth arch.

Muscular elements.—The *muscle mass* of the mandibular arch forms the *tensor veli tympani*, the *tensor palati* and the *muscles of mastication*, including the *mylohyoid* and the *anterior belly of the digastric* (all supplied by the mandibular nerve).

FIG. 129.—The head and neck of a human embryo, eighteen weeks old, with Meckel's cartilage and the hyoid bar exposed. (After Kölliker.)



The *tensor tympani* retains its attachment to the skeletal element of the arch, but the muscles of mastication transfer their attachment to the mandible. The muscles of the hyoid arch for the most part migrate widely from their original position, but they retain their nerve-supply from the facial nerve. The *stapedius*, the *stylohyoid* and the *posterior belly of the digastric muscle* retain their attachment to the skeletal element of the arch, but the *muscles of facial expression*, the *platysma*, the *auricular* and the *epicranii muscle* lose all connexion with it. Their migration is facilitated by the obliteration of the first cleft and pouch in their ventral parts (p. 117).

The muscle masses of the remaining arches form the *muscles of the pharynx*, *soft palate* and *larynx*. The *stylo-pharyngeus* can be attributed definitely to the third, the *cricothyroid* to the fourth and the remaining laryngeal muscles to the sixth arch, but the precise origin of the constrictor muscles and the muscles of the soft palate is uncertain.

Neural elements.—The *nerves* of the arches are derived from the hind-brain and at once enter the dorsal ends of their arches (fig. 119). Typically, they are mixed nerves; their motor branches supply the muscle of the corresponding arch and their sensory branches are distributed to the skin and mucous membrane derived from it. In fishes the nerves and their ganglia lie at the dorsal ends of the clefts, and each sends a pre-trematic branch into the arch on the cephalic side of its cleft and a post-trematic branch into the arch on its caudal side. In mammals, although both may be distinguished in the first arch, only one nerve can be identified with certainty in the second, third, fourth and sixth arches, while the nerve of the fifth arch is unknown and may have disappeared.

The mandibular division of the trigeminal nerve is the post-trematic nerve of the first arch, and the chorda tympani is the pretrematic nerve to this arch.* The facial supplies the second arch, the glossopharyngeal the third, the superior laryngeal nerve the fourth, and the recurrent laryngeal nerve the sixth. In lower animals the nerve to the fifth arch is a branch of the vagus.

The difference in the behaviour of the recurrent laryngeal nerves on the two sides of the body in the adult can be understood on reference to the history of the aortic arches. The nerve enters the sixth visceral arch caudal to the sixth aortic arch. It retains this position on the left side of the body, and in the adult is found on the left side of (i.e. caudal to) the ligamentum arteriosum. On the right side, however, owing to the disappearance of the dorsal part of the sixth aortic arch and of the whole of the fifth aortic arch, the nerve is found on the caudal aspect of the subclavian artery, i.e. the fourth aortic arch.

Pharyngeal pouches.—The first four pharyngeal pouches (pouches I–IV) arise in sequence from before backwards and their entoderm approaches the ectoderm of the overlying branchial clefts to form thin membranes termed the *closing membranes* (fig. 119). At their lateral ends the second, third and fourth pouches are prolonged dorsally and ventrally to form angular recesses or wings. From the fourth pouch a diverticulum grows in a caudal and ventral direction and is at first demarcated on its lateral aspect from the fourth pouch by a groove in which there may occur a transient fifth aortic arch artery. From this diverticulum a fifth pouch may or may not develop and establish a connexion with the ectoderm. The remainder of the diverticulum is termed the *ultimo-branchial body*. This with the fourth pharyngeal pouch and the transitory fifth pouch, when present, together constitute the *caudal pharyngeal complex*. Its communication with the pharynx is termed the *common pharyngobranchial duct*.

The further development of the entodermal derivatives of the pharynx and of the pharyngeal pouches is equivalent to the description of the development of the mouth, pharynx and larynx and will, therefore, be considered later (p. 181).

The development of a diverticulum which is usually termed the ultimobranchial body, in association with the last pharyngeal pouch or immediately caudal to it is an almost constant feature in the vertebrates. This diverticulum never extends laterally towards the ectoderm and cannot be regarded as a modified pharyngeal pouch.

THE LOCOMOTOR APPARATUS

The limbs.—Towards the end of the fourth week the limbs appear as small elevations or buds from a slight lateral ridge at either side of the trunk (figs. 117 and 242). Prolongations from several primitive segments extend into each bud, and carry with them the ventral rami of the corresponding spinal nerves; the nerves supplying the limbs indicate the number of primitive segments which contribute to their formation—the upper limb being derived from seven, viz. fourth cervical to second thoracic inclusive, and the lower limb from ten, viz. twelfth thoracic to fourth sacral inclusive. The axial part of the mesenchyme of the limb-bud condenses and is converted into its cartilaginous skeleton, and by the ossification of this the bones of the limbs are formed. The musculature of the limbs is developed *in situ* from the mesoderm which surrounds the developing skeletal elements, and such muscles as the latissimus dorsi, which possess an extensive attachment to the axial skeleton in the adult, gain that attachment secondarily during intrauterine life, as the result of active migration.

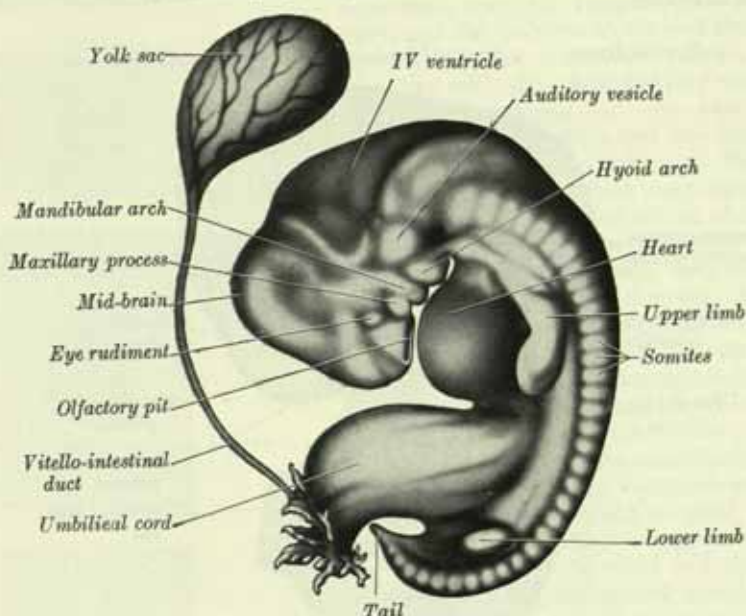
In the early stages the growth of both the upper and the lower limb-buds follows the same pattern until the end of the sixth week, but the upper limb-bud appears before the lower and is always a few days in advance of it in its development (fig. 130). Flexion creases indicate the sites of the elbow, wrist, knee and ankle and the hand and foot are represented by flattened plate-like expansions (fig. 131). By the latter part of the sixth week there is still little difference in posture between the two limbs, the long axis of each is approximately at right angles to the trunk and the points of the elbow and knee are directed *laterally* (fig. 131). At this stage the

* J. Ernest Frazer did not regard the chorda tympani as a pretrematic nerve, for reasons explained in his *Manual of Embryology*.

cranial (or *preaxial*) borders of both limbs are directed headwards, while their caudal (or *post-axial*) borders are directed tailwards.

In the two succeeding weeks growth changes are imposed on the limbs so that they become adducted towards the trunk and flexion is increased both at the elbow and at the knee. By the end of the eighth week the limbs have adopted the foetal position, the elbow being directed *caudally*, and the knee *towards the head* (fig. 246). This conspicuous and important difference is due to the occurrence of rotation of the limbs in opposite directions around their long axes, for simultaneously with the process of adduction the upper limb becomes rotated laterally, while the thigh is rotated in a medial direction. As a result the originally ventral or flexor surface of the arm becomes anterior, but the corresponding surface of the thigh becomes posterior. This change necessarily imposes similar changes in the forearm and leg, so that the flexor surface of the forearm ultimately becomes the anterior surface, while the flexor surface of the leg becomes its posterior surface.

FIG. 130.—A human embryo about 9 mm. long. At end of fifth week. (Drawn from a stereoscopic photograph of embryo after fixation.)



In addition, the radius, which is the preaxial bone of the forearm, comes to lie on the lateral side of the ulna, whereas the tibia, which is the preaxial bone of the leg, comes to lie on the medial side of the fibula. The hand and foot are also affected and the preaxial digit (the thumb) comes to lie laterally in the hand, while the homologous digit in the foot (the hallux) lies on the medial side when the foot becomes fully plantigrade in early childhood.

For these reasons the preaxial border ultimately runs down the lateral aspect of the upper limb and its cutaneous innervation is therefore derived from the upper nerves of the brachial plexus (C. 4-7) (fig. 988), whereas the postaxial border runs down the medial aspect and derives its cutaneous innervation from the lower nerves of the plexus (C. 8-T. 2). In the lower limb the plan is similar but is not so apparent, although there is a distinct tendency for the upper nerves (L. 1-4) to be distributed along the medial aspect, while the lower nerves (L. 5-S. 3) supply the lateral aspect (figs. 990, 991). (See also p. 1192.)

It must be remembered that, as the joint cavities do not appear before the third month, the changes in posture which the developing limbs exhibit, particularly in the latter part of the second month, are not effected by muscular action at the joints but are imposed on them by differential growth changes especially in the skeletal elements.

The foot and hand resemble each other closely at first, each being represented by a plate-like enlargement at the extremity of the bud. The mesenchymal core of the

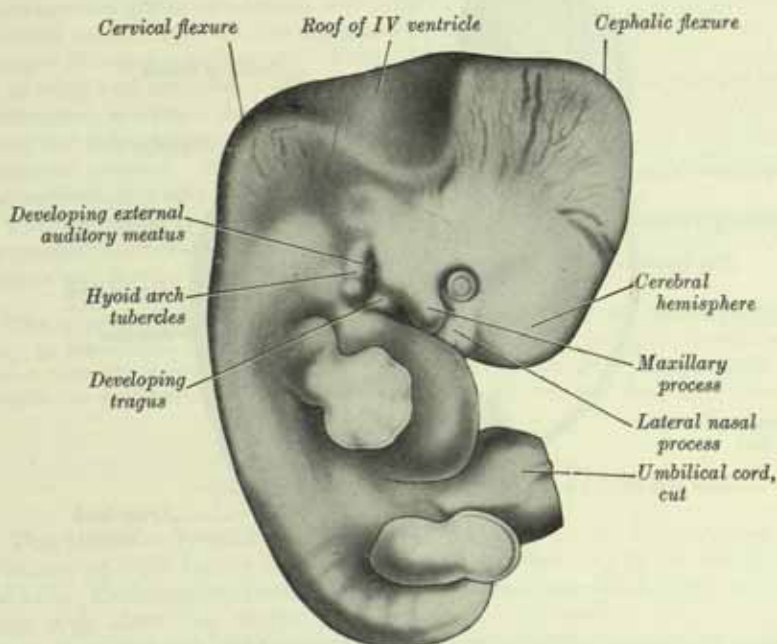
peripheral part of the plate becomes condensed to outline the digits, and the thinner, intervening areas break down from the circumference towards the centre. This process may be carried out incompletely or it may be prematurely arrested, and in such cases varying degrees of *webbing of the fingers or toes* are present at birth.

The ossification of the limb-bones is described along with the description of the individual bones.

The joints.—The mesenchyme from which the different parts of the skeleton are formed shows no differentiation at first into masses corresponding with the individual bones; thus, continuous cores of mesenchyme form the axes of the limb-buds and a continuous column of mesenchyme the future vertebral column. The first indications of the differentiation of the bones and joints are circumscribed condensations of the mesenchyme; these condensed parts become chondrified and finally ossified to form the bones of the skeleton. The intervening non-condensed

FIG. 131.—A human embryo, 15.5 mm. long. (G. L. Streeter, *Contr. Embryol.*, Carneg., Instn., 32, 1948.)

Compare the upper and lower limb buds, as regards their differentiation and degree of rotation.



portions consist at first of undifferentiated mesenchyme, which may be converted into fibrous tissue as in the case of the skull bones, a fibrous joint being the result; or it may become partly fibrocartilaginous, in which case a cartilaginous joint is formed; or it may become looser in texture, a cavity ultimately appearing in its midst, while the cells lining the sides of this cavity form a synovial stratum, and thus a synovial joint is developed; in some synovial joints portions of the mesenchyme persist and form menisci. The process of cavity formation is brought about partly by widening of the spaces in the mesenchymal reticulum and by disappearance of its fine protoplasmic bridges, and partly by liquefaction of the cell elements.*

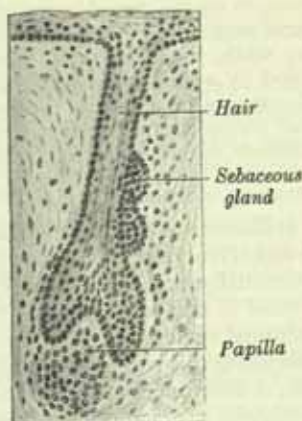
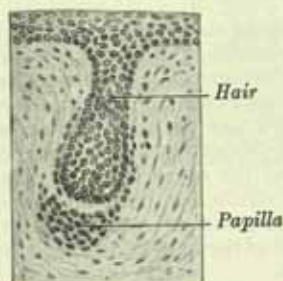
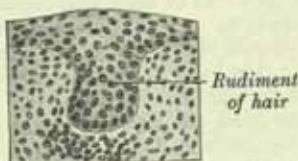
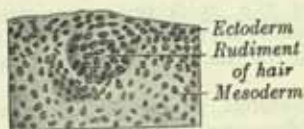
The tissue surrounding the original mesenchymal core forms fibrous sheaths for the developing bones (perichondrium and periosteum), which are continued over the synovial strata as the fibrous membranes of the capsules of the joints between the ends of the bones. These capsules are not of uniform thickness, and specially strengthened bands—the precursors of ligaments—can be recognised in them. This, however, is not the only method of formation of ligaments. In some cases, by

* For a detailed description of the development and structure of the synovial membrane, see D. V., Davies, *B.M.J.*, i, 1950.

modification of, or derivation from, the tendons surrounding the joint, additional ligamentous bands are provided to strengthen the articulations.

The muscles.—With the exception of certain muscles of the head and neck, which are developed from the mesenchymal cores of the visceral arches (p. 119), and the muscles of the limbs, which develop *in situ* from the mesenchyme of the limb-buds (p. 120), all the *voluntary muscles* of the body are derived from the myotomes (p. 79). Typically, each myotome divides into a dorsal and a ventral portion. The former takes up its position on the dorsolateral aspect of the vertebral column and is innervated by the dorsal ramus of the corresponding spinal nerve; the cells of the

FIG. 132.—Successive stages in the development of a hair.



latter migrate ventrally into the body-wall or somatopleure and are innervated by the corresponding ventral ramus. In fishes these two primary subdivisions of the myotomes are separated from each other by the transverse processes of the vertebræ and a fibrous septum which extends from them to the lateral line. The pre-muscle masses, derived from the myotomes, may split longitudinally or tangentially, and the portions so derived may remain separate, e.g. the intercostal muscles, or they may fuse with the corresponding portions of adjoining myotomes, e.g. the external and internal oblique muscles and the transversus. In mammals the derivatives of the ventral portions of the myotomes may subsequently migrate so as to cover derivatives of the dorsal portions, but, as their nerve-supply is determined at a very early stage, they carry their nerves with them as they migrate. As a result such muscles as the serratus posterior, superior and inferior, which are attached to the vertebral spines and cover the erector spinæ muscle, are supplied by anterior primary rami because they have been derived from the ventral portions of certain myotomes and have secondarily acquired their adult position and vertebral attachment. Numerous examples could be cited, but those already given will suffice to suggest others.

The muscles of the orbit and the muscles of the tongue require special mention. The hypoglossal nerve, as will be pointed out later, is a compound nerve and is serially homologous with the anterior nerve roots of the spinal nerves. Its inclusion within the skull is secondary. The myotomes of the corresponding somites, probably four in number, migrate from their original site into the tongue, carrying their nerve-supply with them (p. 117).

No mesodermic somites have yet been observed in the head region of the human embryo, but, on the evidence of comparative anatomy, it seems probable that a large number of somites, seven or more, originally developed in this situation. Of the corres-

ponding myotomes, however, portions of only three persist, and they form the muscles supplied by the oculomotor, trochlear and abducent nerves.

In man and the higher vertebrates many of the derivatives of the myotomes degenerate and some disappear entirely. Others are converted into fibrous tissue, which may take the form of aponeuroses (e.g. the aponeuroses of the abdominal muscles) or ligaments (e.g. the sacrotuberous ligament).

The *involuntary muscles* are derived from the mesoderm of the splanchnopleure and develop *in situ* (p. 81).

THE SKIN AND ITS APPENDAGES

The epidermis, hairs, nails, sebaceous and sudoriferous glands are developed from the ectoderm, the corium or true skin from the somatic layer of the mesoderm with contributions from the dorsilateral walls of the mesodermal somites (p. 79). The ectoderm at first consists of a single stratum of cells, but in the sixth week two strata can be recognised, a superficial, named the *epitrichium*, consisting of flat cells, the nuclei of which stain readily, and a deep, named the *stratum germinativum*, consisting at first of cubical cells, but later of columnar. By multiplication and differentiation of the cells of the stratum germinativum the different layers of the epidermis are developed. Towards the end of the third month the mesoderm condenses to form the corium, and at about the same time the subcutaneous areolar tissue is differentiated; in the fourth month the dermal papillæ begin to make their appearance. A considerable desquamation of the epidermis takes place, and this desquamated epidermis, mixed with sebaceous secretion, constitutes the *vernix caseosa*, with which the skin is smeared during the last three months of fetal life.

The *hairs* (fig. 132) originate as epidermal thickenings, which grow obliquely downwards as solid buds into the corium, each bud consisting of an outer stratum of columnar cells and a core of polygonal cells. The deep end of each bud expands to form the hair-bulb, which is moulded over a papilla of condensed mesoderm. The cells of the hair-bulb proliferate and form a cone of cells, from which the scapus or shaft of the hair and its inner sheath are developed; the hairs gradually lengthen by growth at the hair-bulb, and ultimately project on the surface.

The *sebaceous glands* originate as lateral outgrowths from the sides of the hair-buds, and, pushing their way into the mesenchyme, divide into three or four oval or flask-shaped alveoli, the lining cells of which are derived from the stratum germinativum.

The rudiments of the *sudoriferous* or *sweat glands* make their appearance on the palms of the hands and soles of the feet in the fourth month, and closely resemble the rudiments of the hairs, each beginning as a solid downgrowth of the ectoderm. The ectodermal downgrowth lengthens, and its deeper part coils on itself and forms the body of the gland. A lumen is developed in the downgrowth about the seventh month of intrauterine life, and opens on the surface by a duct which is lined with two layers of cells. In the secreting part of the gland the outer layer of cells is modified to form a stratum of smooth muscle-fibres, which lies between the epithelium of the gland and the basement-membrane. Many sudoriferous glands arise as ectodermal downgrowths from the superficial portions of the hair-follicles and later acquire independent openings on the surface of the skin.

The rudiments of the *nails* can be seen in embryos of about 4.5 cm. in length (third month), and appear as *primary nail-fields* of ectoderm on the dorsal surfaces of the distal phalanges of the digits. At the proximal end and sides of each nail-field the epidermis is invaginated to form the nail-folds, while the distal end, which will ultimately form the free end of the nail, is bounded by a shallow groove. The nail is developed from the posterior nail-fold and consists of modified stratum lucidum. The stratum corneum covers the nail and forms the *eponychium*; this disappears from the surface of the nail, with the exception of a narrow fold which overlaps the proximal part of the lunule.

The *mammary gland* may be looked upon as a collection of greatly modified sudoriferous glands; the epithelial lining of its ducts and alveoli is derived from the ectoderm, its supporting connective tissue from the mesenchyme. On each side of the ventral surface of young embryos a thickened band of ectoderm, termed the *milk-ridge*, extends obliquely from the axilla to the inguinal region, and in some of the lower mammals mammae are developed at intervals along this ridge; in man, no definite ridge is found, and only one mamma, as a rule, is developed on each side of the median plane, but supernumerary mammae or nipples are sometimes found above or below the fully developed gland.

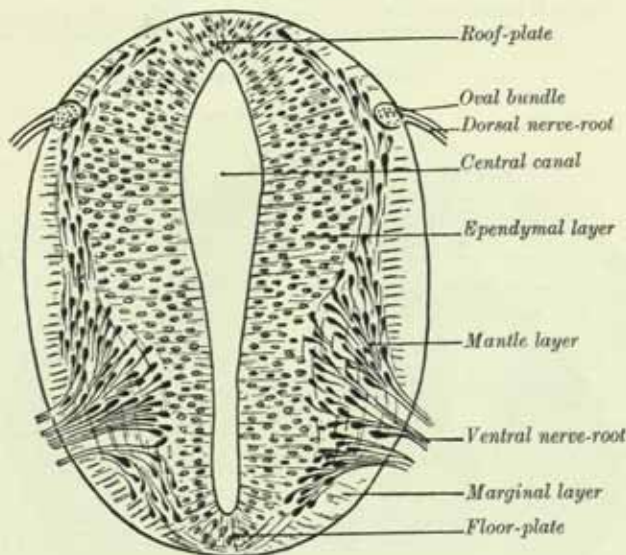
The rudiment of the mammary gland appears as a thickening and subsequent ingrowth of the ectoderm; from this ingrowth fifteen or twenty solid cords branch off, each cord representing a future lactiferous tubule and lobe of the gland. The deep ends of the cords subdivide in the mesenchyme and form the alveoli of the gland. In the latter weeks of fetal life the tubules and alveoli become canalised, and the lactiferous tubules then open into the floor of an epidermal pit. Just before or soon after birth, the mesenchyme underlying this depression proliferates and the pit becomes everted to form the nipple. At the age of puberty, and in a greater

degree towards the end of pregnancy, a marked enlargement of the gland and a development of additional lobules and alveoli takes place.

THE DEVELOPMENT OF THE NERVOUS SYSTEM AND SENSE-ORGANS

The appearance of the medullary plate and its further differentiation into a median neural groove limited on each side by neural folds which fuse with each other during the fourth week to form a neural tube, have already been described (p. 76). The cephalic end of the neural tube develops into the brain and its

FIG. 133.—A transverse section through the spinal medulla of a human embryo four weeks old. (His.)



ventricles, and the remainder of the tube forms the spinal medulla and its central canal.

The spinal medulla.—At the time when the neural tube is closing the cells forming its walls, initially consisting of a single layer of columnar epithelium, are proliferating rapidly. The lateral walls of the tube consequently thicken and are soon differentiated into three layers, an inner or *ependymal layer*, an intermediate or *mantle layer* and an outer or *marginal layer* (fig. 133). The inner and outer aspects of the walls of the neural tube are bounded by *inner* and *outer limiting membranes*. The ependymal layer gives rise to cells which migrate into the mantle layer and also to the ependymal cells which subsequently line the central canal. The cells of the mantle layer are of two varieties termed *spongioblasts* and *neuroblasts*. The former give rise to the astrocytes and oligodendrocytes of the neuroglia (p. 38), and the latter to nerve cells. Increase in the number of cells in the mantle layer is brought about partly by subdivision of its constituent cells and partly by continued migration of cells into it from the ependymal layer. The marginal layer consists of the non-nucleated cytoplasm of the spongioblasts and forms a framework for the various tracts by which it is subsequently invaded. The *roof-plate* and *floor-plate* of the neural tube do not participate in the cellular proliferation affecting the lateral walls and remain thin.* Their cells contribute only to the formation of ependyma.

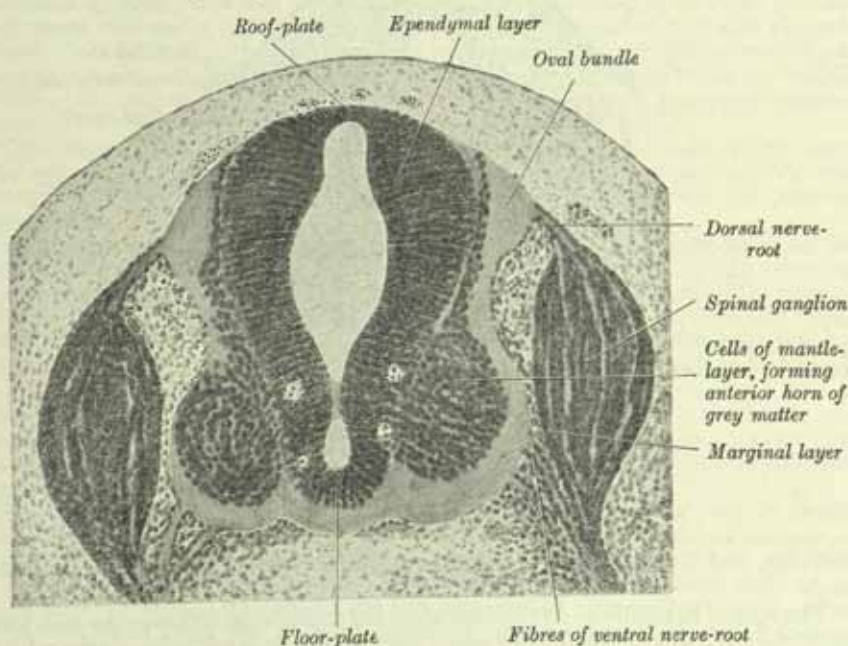
The neuroblasts are large and at first round or oval in shape. Soon they develop axonal processes at opposite poles and become *bipolar neuroblasts*. One of these processes is, however, withdrawn and the neuroblast becomes unipolar. Further differentiation leads to the development of dendritic processes and they become typical multipolar nerve cells. In the developing spinal medulla the nerve cells occur

in small clusters and two or more of them may be connected to one another by their apical processes. Such groups represent nerve cells undergoing rapid division.

At first the neural tube is oval in outline and its lumen is narrow and slit-like (fig. 133). As the lateral walls thicken the lumen widens in its dorsal part and presents a somewhat lozenge-shaped appearance on cross-section (fig. 135A). The widening of the canal is associated with the development of a longitudinal *sulcus limitans* on the inner wall on each side. This subdivides each lateral wall into a ventral or *basal lamina* and a dorsal or *alar lamina*. This separation is fundamental and indicates a functional difference, for the nerve cells in the basal lamina become the motor cells of the anterior and lateral grey columns, while those of the alar lamina form neurones on the afferent, sensory pathways. At its caudal end the central canal of the spinal medulla exhibits a fusiform dilatation which is known as the *terminal ventricle*.

The cells of the ependymal layer are closely packed at this stage and tend to

FIG. 134.—A transverse section of the spinal medulla in the cervical region of a human embryo early in the sixth week. (C. R. length = 8 mm.)



arrange themselves in radial columns (fig. 134). The cells of the mantle layer are more loosely arranged, and they increase in number at first in the region of the basal lamina. This enlargement outlines the *anterior column* of the grey matter and it causes a forward projection on each side of the median plane, the floor-plate remaining at the bottom of the shallow groove so produced. As growth proceeds, these enlargements, further increased by the development of the anterior funiculi, encroach on the groove until it becomes converted into the slit-like anterior median fissure of the adult spinal medulla (fig. 135, A and B). The axons of the nerve-cells in the anterior grey column traverse the marginal zone and emerge on the anterolateral aspect of the spinal medulla as the *ventral nerve roots*.

In the thoracic and upper lumbar regions the cells of the mantle layer in the dorsal part of the basal lamina outline a *lateral column*. The axons of its cells join the emerging ventral nerve roots and pass through white rami communicantes to the ganglia of the sympathetic trunk to be distributed to the viscera and blood-vessels. At the same time a lateral column is laid down in the mid-sacral region also, and gives origin to the parasympathetic fibres which form the pelvic splanchnic nerves (p. 1200).

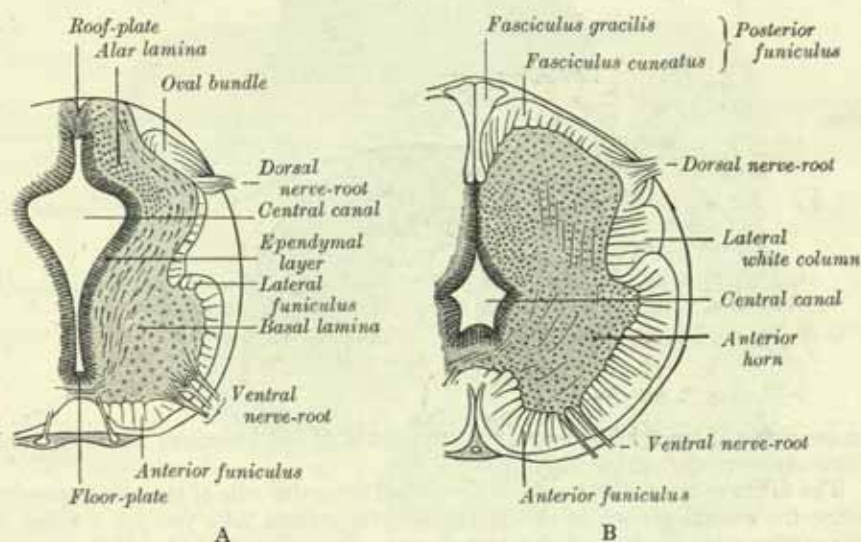
As the anterior and lateral grey columns assume their final form the cells in the ventral part of the ependymal layer gradually cease to proliferate, and the layer

becomes reduced in thickness until it ultimately forms the single-layered ependyma which lines the ventral part of the central canal of the spinal medulla. The *posterior column* is somewhat later in its development, and, as a result, the ependymal layer is for a time much thicker in the alar lamina than it is in the basal lamina (fig. 134).

While the columns of grey matter are being defined, the dorsal portion of the central canal becomes narrow and slit-like, and its walls come into apposition and fuse with each other (fig. 135). In this way the central canal becomes considerably reduced in size and somewhat triangular in outline.

About the end of the fourth week nerve-fibres appear in the marginal layer. The first to develop are the short intersegmental fibres from the neuroblasts in the mantle zone, and the fibres of the *dorsal roots* of the spinal nerves which pass into the spinal medulla from the cells of the spinal ganglia. By the sixth week the latter form a well-defined *oval bundle* in the peripheral part of the alar lamina (fig. 134); this bundle increases in size, and spreading towards the median plane forms the rudiment of the posterior funiculus. As the posterior funiculi increase in thickness, their opposed medial surfaces come into contact with each other, but are

FIG. 135.—Transverse sections through the spinal medulla of a human embryo. A, about six weeks old. B, about three months old. (His.)



separated by the *posterior median septum*, which is ependymal in origin, neuroglial in nature. The long intersegmental fibres begin to appear about the third month, and the corticospinal fibres about the fifth month. All nerve-fibres are at first destitute of medullary sheaths, and different groups of fibres receive their sheaths at different times, e.g. the ventral and dorsal nerve-roots are medullated about the fifth month, the corticospinal fibres after the ninth month. The source of the myelin is uncertain. In the case of the peripheral nerves its formation has been attributed to the cells of the nucleated neurolemmal sheaths, whilst in the central nervous system the oligodendrocytes are believed to be concerned.

The cervical and lumbar enlargements appear simultaneously with the development of the limb-buds.

In early embryonic life the spinal medulla occupies the entire length of the vertebral canal, and the spinal nerves pass outwards at right angles. After the embryo has attained a length of 30 mm. the vertebral column begins to grow more rapidly than the spinal medulla, the caudal end of which gradually assumes a higher position within the vertebral canal. The principal part of this upward migration occurs during the first half of intrauterine life. By the twenty-fifth week the terminal ventricle of the spinal medulla (p. 933) has ascended from the level of the second coccygeal vertebra to that of the third lumbar vertebra, or a distance of nine segments, and there remain but two segments before the adult position is reached (Streeter *).

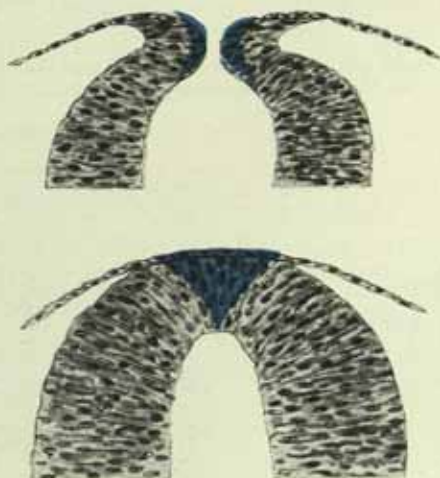
* G. L. Streeter, *Amer. J. Anat.*, 25, 1919.

As the migration upwards commences, the caudal end of the terminal ventricle, which has become adherent to the overlying ectoderm, remains *in situ*, and the walls of the intermediate part of the ventricle and its covering pia mater become drawn out to form a delicate filament, termed the *filum terminale*. The separated portion of the terminal ventricle persists for a time but it disappears before birth as a rule. It does, however, occasionally give rise to congenital cysts in the neighbourhood of the coccyx.

The spinal nerves.—Each spinal nerve is attached to the spinal medulla by a ventral root and a dorsal root.

The fibres of the ventral roots are formed by the axons of the neuroblasts which lie in the anterior and lateral parts of the mantle layer; these axons pass out through

FIG. 136.—Two stages in the development of the neural crest in the chick embryo. The cells of the crest are shown in blue.

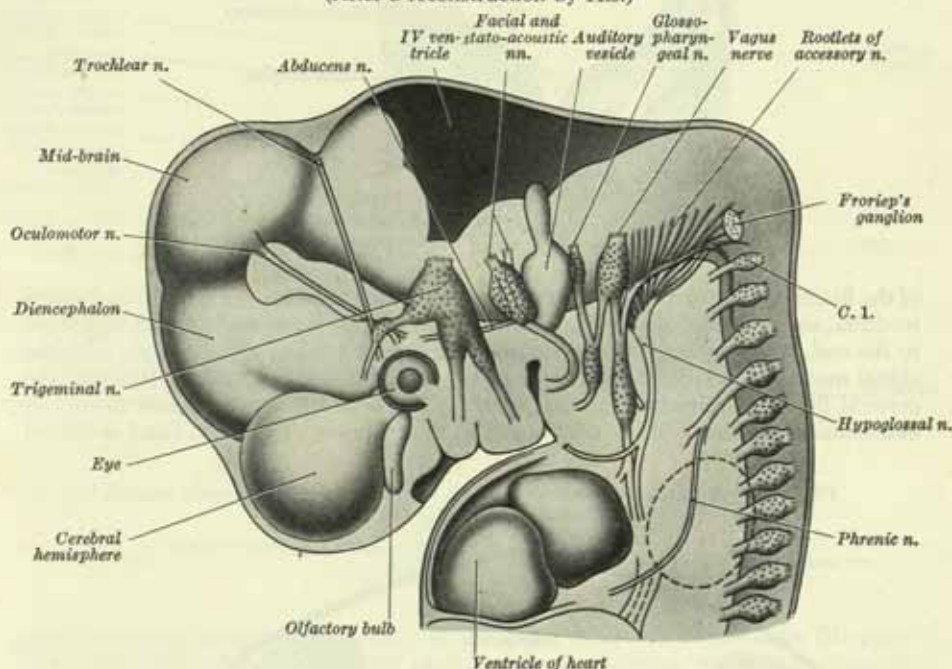


the overlying marginal layer into the myotomes of the primitive segments, and ultimately form the ventral nerve-roots.

The fibres of the dorsal roots are developed from the cells of the spinal ganglia. Before the neural groove is closed to form the neural tube (p. 77) a ridge of neuroectodermal cells, termed the *neural crest* or *ganglion-ridge* (fig. 136), appears along the prominent margin of each neural fold. When the folds meet in the median plane the two ganglion-ridges fuse and form a wedge-shaped area along the line of closure of the tube. Opposite the primitive segments the cells of this area proliferate rapidly to form a series of oval-shaped masses, termed the *primitive spinal ganglia*, and these migrate for a short distance in a lateral and ventral direction. From the ventral part of each mass a small portion is detached to form sympatho-chromaffin cells (p. 145), while the remainder is converted into a spinal ganglion. The spinal ganglia are arranged symmetrically at the sides of the neural tube and, except in the region of the tail, are equal in number to the primitive segments. The cells of the ganglia, like the cells of the mantle layer, are of two kinds, viz. spongioblasts and neuroblasts. The spongioblasts develop into the neuroglial cells of the ganglia, the nucleated capsules of the ganglion cells and the neurolemma sheaths of the spinal nerves. The neuroblasts, at first round or oval in shape, soon assume the form of spindles, the extremities of which gradually elongate into central and peripheral processes. The central processes grow into the wall of the neural tube, and constitute the fibres of the dorsal nerve-roots, while the peripheral processes grow forwards to mingle with the fibres of the ventral root in the spinal nerve. As development proceeds the original bipolar form of the cells in the spinal ganglia changes; the two processes become approximated until they ultimately arise from a single stem in a T-shaped manner. The bipolar form is retained in the retina and in the ganglia of the auditory nerve. Some observers hold that the T-form is derived from the branching of a single process which grows out from the cell.

The precise manner in which a motor nerve-cell establishes contact with its effector is still uncertain. On the whole, the balance of the evidence, both embryological and experimental, supports the view that the axon grows out from the body of the cell and finds its way to the effector, and that the processes of the sensory nerve-cells develop in the same way. On the other hand, many embryologists maintain that, from the earliest stages of development, the motor cells are in direct connexion with the mesodermal muscle cells by means of protoplasmic bridges and that this connexion, though it may undergo considerable lengthening, is never lost. Harrison* carried out a long series of experiments, chiefly on amphibian larvæ, which all tend to support the view that the axons grow out actively from the nerve-cells. The same observer and others have succeeded in culturing nerve-cells *in vitro*, and they have found that in the complete absence of other tissues the cells give rise to long processes which, so far as can be ascertained, are identical with axis cylinder processes. The opponents of this view depend mainly on histological observations.

FIG. 137.—The brain and cranial nerves of a human embryo, 10.2 mm. long.
(After a reconstruction by His.)



The cells which form the neurolemmal sheaths of the peripheral nerves have been ascribed to a variety of sources. Harrison† excised the neural crest in young amphibian larvæ and discovered that the motor fibres derived from the corresponding portion of the neural tube developed as naked axons. Later, however, these fibres acquired a neurolemmal sheath, the constituent cells migrating from the wall of the neural tube. He came to the conclusion that the sheaths are neuroectodermal in origin, formed partly from the cells of the neural crest and partly from the cells of the neural tube.

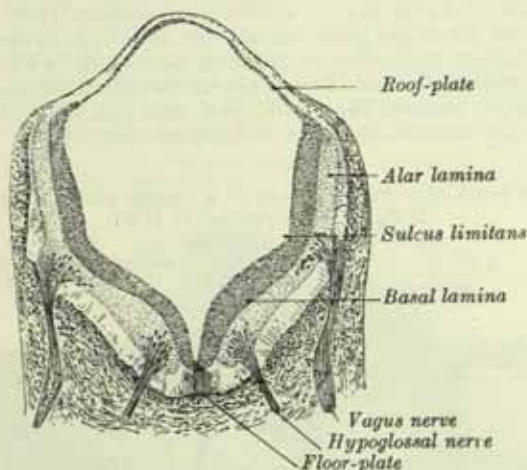
The brain.—Prior to the closure of the neural tube the neural folds become expanded considerably in the head region to outline the brain (fig. 80). Subsequent to the closure of the anterior neuropore (p. 77) these expansions form the three primary cerebral vesicles (fig. 142). These are marked off from each other by constrictions, and are named the *rhombencephalon* or *hind-brain*, the *mesencephalon* or *mid-brain*, and the *prosencephalon* or *fore-brain*—the first being continuous with the spinal medulla. As the result of the unequal growth of its different parts three flexures appear in the brain; two of these flexures are concave ventrally and are associated with corresponding flexures of the head. The first is associated with the formation of the head fold. It appears in the region of the mid-brain, and is named the *cephalic flexure* (fig. 137); the fore-brain bends in a ventral direction

* R. G. Harrison, *Amer. J. Anat.*, 5, 1906, and *Anat. Anz. Erg.*, 85, 1937.

† R. G. Harrison, *J. Comp. Neur.*, 1924.

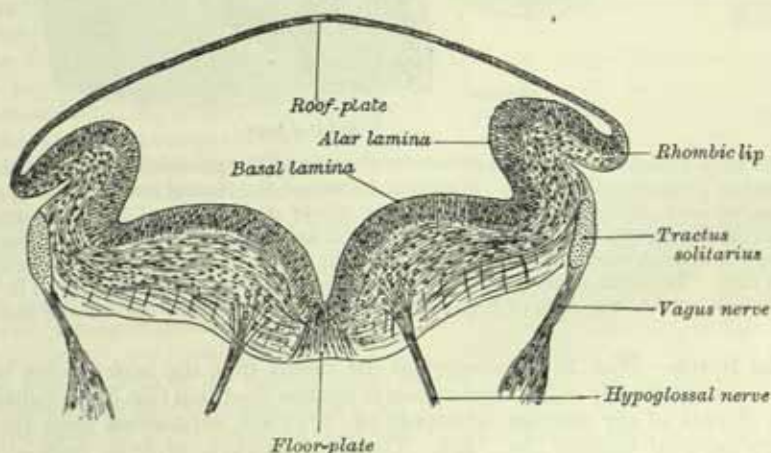
around the cephalic end of the notochord and fore-gut until its floor lies almost parallel with that of the hind-brain (fig. 137). The mid-brain is for a time the most prominent part of the brain, since its dorsal surface corresponds with the convexity

FIG. 138.—A transverse section through the medulla oblongata of a human embryo, 10.2 mm. long. $\times 32$. (From Kollmann's *Entwicklungsgeschichte*.)



of the flexure. The second bend appears at the junction of the hind-brain and spinal medulla, and is termed the *cervical flexure* (fig. 137). It increases from the fifth week to the end of the seventh, when the hind-brain forms nearly a right angle with the spinal medulla; after the seventh week extension of the head takes place and the cervical flexure diminishes and disappears. These bends are important factors in determining the shape of the cranial end of the embryo. The third bend is named

FIG. 139.—A transverse section through the medulla oblongata of a human embryo. (After His.)



the *pontine flexure* (fig. 141), because it is found in the region of the future pons. It differs from the other two in that (a) its convexity is directed ventrally, and (b) it does not affect the head.

The lateral walls of the hind-brain and mid-brain, like those of the spinal medulla, are divided into dorsal or alar and ventral or basal laminae (fig. 138) by the upward continuation of the limiting sulci of the spinal medulla.

The rhombencephalon or hind-brain.—By the time the cephalic flexure appears, the hind-brain exceeds in length the combined lengths of the other two

brain vesicles. At its cephalic end it exhibits a constriction termed the *isthmus rhombencephali* (fig. 142, Isthmus), which is best seen when the brain is viewed from the dorsal aspect. Ventrally it is separated from the dorsal wall of the primitive pharynx only by the notochord, the two dorsal aortæ, and a small amount of mesenchyme, and on each side it is closely related to the dorsal ends of the visceral arches (fig. 119).

The formation of the pontine flexure throws a strain on the thin, epithelial roof-plate, which becomes stretched and widened, the maximum increase in width corresponding to the region of maximum convexity, so that the outline of the roof-

FIG. 140.—Diagram of a transverse section through the developing hind-brain of a human embryo, 6 10·5 mm. long, to show the relative positions of the nuclei of the different varieties of nerve components.

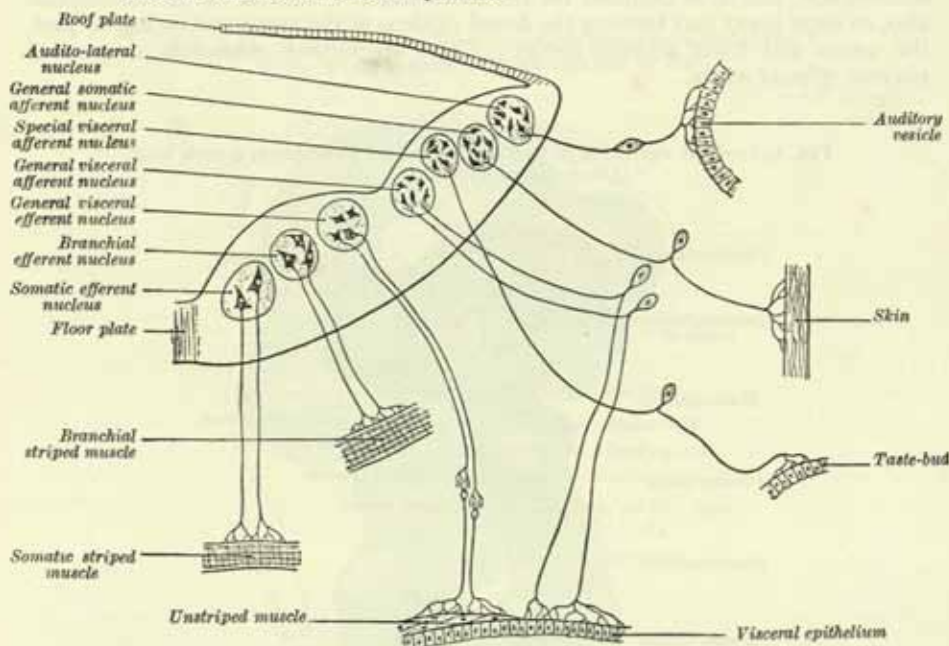


plate becomes rhomboidal in form. At the same time, the lateral walls fall away from each other (fig. 139) and the cavity of the hind-brain, which subsequently forms the fourth ventricle, becomes flattened and somewhat triangular on cross-section. The pontine flexure becomes more and more acute until, at the end of the second month, the alar and basal laminae of its cephalic (metencephalon) and caudal (myelencephalon) slopes are opposed to each other (fig. 144) and, at the same time, the lateral angles of the cavity become drawn out to form the lateral recesses of the fourth ventricle.

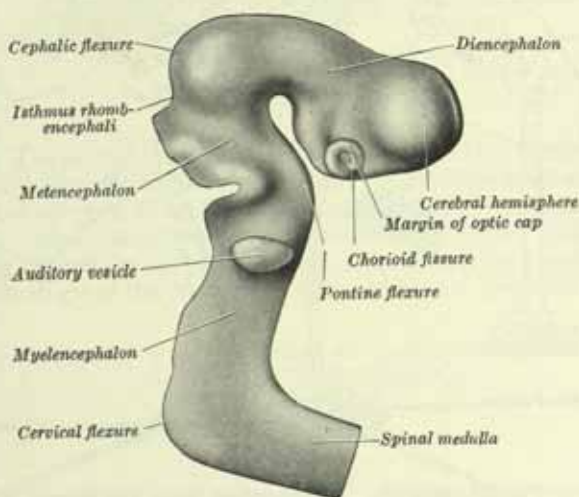
About the end of the fourth week, when the pontine flexure is beginning to be discernible, a series of six transverse grooves appears in the basal lamina of the hind-brain. These are termed the *rhombic grooves* and they bear a very definite relationship to the motor nuclei of certain of the cranial nerves. The first two overlie the nucleus of the trigeminal nerve; the third overlies the nucleus of the facial nerve, the fourth that of the abducent nerve, the fifth that of the glossopharyngeal and the sixth that of the vagus nerve. These grooves, though transient, are constant in character but their significance is uncertain. Some authorities * regard them as evidence in support of the neuromeric origin of the brain and spinal medulla.

The differentiation of the lateral walls of the hind-brain into basal and alar laminae has a similar significance to the corresponding differentiation in the lateral wall of the spinal medulla (p. 126), and ependymal, mantle and marginal layers are formed in the same way. The cells of the basal lamina are motor in function and they

* H. Berquist. *Acta Zool.* 33, 1952.

form three elongated, but interrupted, columns. The most ventral column is in line with the anterior grey column of the spinal medulla and is destined for the supply of muscles which are myotomic in origin. It is represented in the caudal part of the hind-brain, where it forms the nucleus of the hypoglossal nerve, and it reappears at a higher level as the nucleus of the abducent nerve, both of which are termed *somatic efferent nuclei*. The intermediate column, which is only represented in the upper part of the spinal medulla, is destined for the supply of the musculature derived from the branchial arches. It is interrupted also, but the lower part, which gives fibres to the eleventh, tenth and ninth cranial nerves, forms the elongated nucleus ambiguus. At higher levels this column gives origin to the motor nuclei of the facial and trigeminal nerves. These three nuclei are termed *branchial* (or *special visceral*) *efferent nuclei*. The most dorsal column is represented in the spinal medulla by the lateral grey column and, like it, is destined for the innervation of viscera. It is interrupted also, its large lower part forming the dorsal nucleus of the vagus and its higher part the upper and lower salivary nuclei. These are termed *splanchnic*, or *general visceral, efferent nuclei*.

FIG. 141.—The right side of the brain of a human embryo, 9 mm. long.
(Drawn from a model by His.)



Similar interrupted columns are formed in connexion with the alar lamina and give rise to *general visceral afferent*, *special visceral afferent*, *general somatic afferent* and *special somatic afferent* columns (fig. 140). These columns, like those of the basal lamina, are interrupted and broken up into nuclei. The general visceral afferent column is represented by a portion of the dorsal nucleus of the vagus (see also p. 953), the special visceral afferent column by the nucleus of the tractus solitarius, the general somatic afferent column by the nucleus of termination of the trigeminal nerve and the special somatic afferent column by the nucleus of the auditory nerve. Although they tend to retain their primitive positions some of these nuclei are later displaced by the growth of the fibre tracts through the region or by active migration. Ariëns Kappers* has pointed out that a nerve-cell tends to remain as near as possible to its source of stimulation and that when the danger of separation arises, owing to the development of neighbouring structures, it will migrate in the direction from which the stimuli come. This phenomenon is termed Neurobiotaxis. Cells can migrate in this way only by lengthening of their axons, which therefore map out the route taken by the cell or groups of cells on its transit. The curious course of the fibres arising from the facial nucleus (p. 965) and nucleus ambiguus (p. 957) illustrate the point clearly.

The caudal slope of the hind-brain constitutes the *myelencephalon*, which develops into the medulla oblongata. The nuclei of the ninth, tenth, eleventh and twelfth

* C. V. A. Kappers, *Brain*, 44, 1921, and *Irish Journal of Medical Sciences*, 1934.

cranial nerves develop in the situations already indicated, and afferent fibres from the ganglia of the ninth and tenth nerves form an oval bundle in the marginal zone in the region of the alar lamina (fig. 139). The dorsal edge of the alar lamina throughout the rhombencephalon gives attachment to the thin expanded roof-plate and is termed the *rhombic lip*. As the walls of the rhombencephalon fall outwards, the rhombic lip forms a lateral edge (fig. 139) which becomes folded over the adjoining area. According to the generally accepted view it later becomes adherent to this area, and the cells of the rhombic lip migrate actively into the marginal zone of the basal lamina. In this way the oval bundle of the *tractus solitarius* becomes buried beneath the surface. The cells which migrate from the rhombic lip are believed to give origin to the olivary and arcuate nuclei and the scattered grey matter of the nuclei pontis. While this migration is in progress the thin floor-

FIG. 142.—The brain of a human embryo about 10.2 mm. long.
Right lateral surface. (From a model by His.)

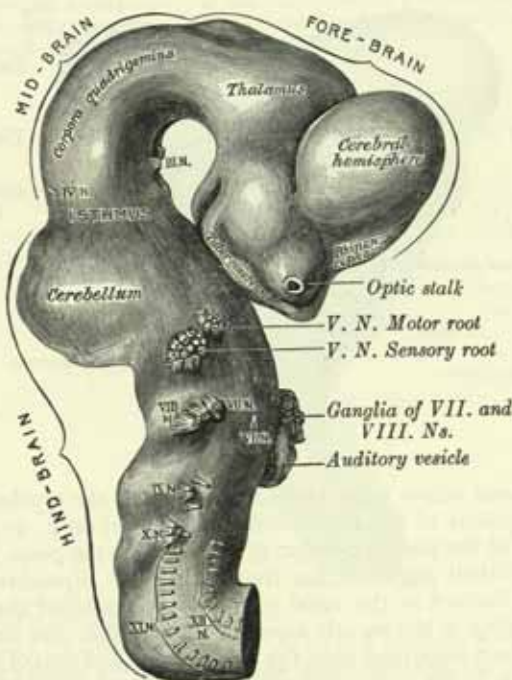


plate is invaded by fibres which cross the median plane, and it becomes thickened to form the median raphe.

The lower part of the myelencephalon takes no part in the formation of the fourth ventricle, and, in its development, it closely resembles the spinal medulla. The large nuclei, gracilis and cuneatus, are derived from the alar lamina, and their efferent arcuate fibres play a large part in the formation of the median raphe.

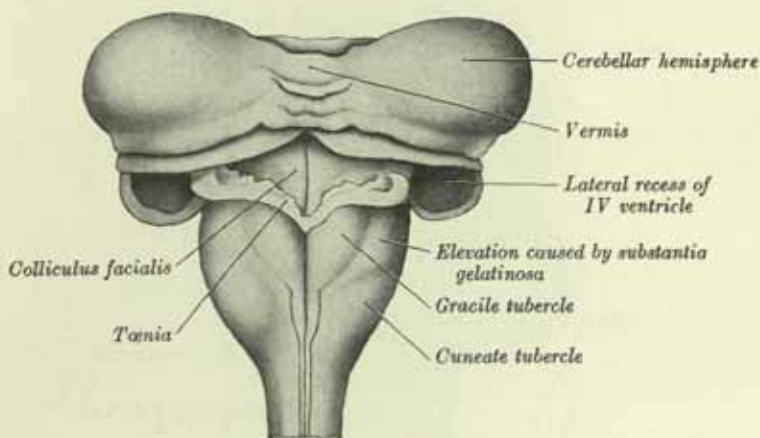
About the fourth month the descending corticospinal fibres invade the ventral part of the medulla oblongata to form the pyramids and ascending fibres from the spinal medulla, together with olivocerebellar and external arcuate fibres, form the inferior cerebellar peduncle.

The upper or headward slope of the hind-brain is termed the *metencephalon* and from it both the cerebellum and the pons are developed. Prior to the formation of the pontine flexure the alar laminae of the metencephalon are parallel with one another. Subsequent to its formation the roof-plate of the hind-brain becomes rhomboidal and the alar laminae of the metencephalon lie obliquely, being close to one another at the headward end of the fourth ventricle, but widely separated in the region of its lateral angles. The accentuation of the pontine flexure approximates the upper angle of the ventricle to the lower

and the alar laminae of the metencephalon now lie almost horizontally and in line with each other.

While these changes are occurring the cells in the rhombic lip and dorsal part of the alar lamina of the metencephalon proliferate to form the rudiment of the cerebellum. Two rounded swellings are formed which, at first, project partly into the ventricle (fig. 144), and they form the rudimentary cerebellar hemispheres. The uppermost part of the roof of the metencephalon originally separates the two swellings, but it becomes invaded by cells, which form the rudiment of the vermis. Frazer* regards these cells as derivatives both of the basal and of the alar laminae. At a later stage the cerebellum forms a dumb-bell shaped swelling stretched across the upper part of the fourth ventricle (fig. 143), continuous above with the anterior medullary velum, which has formed

FIG. 143.—The cerebellum of a foetus in the fifth month. (From Kollmann's *Entwicklungsgeschichte*.)



from the isthmus, and below with the epithelial roof of the myelencephalon. The subsequent development of the cerebellum is described on p. 973.

The remainder of the metencephalon gives origin to the pons, but very little is known of the individual stages in the transformation. Ependymal, mantle and marginal zones are formed in the usual way, and the nuclei of the fifth, sixth and seventh nerves develop in the mantle layer. It is probable that the grey matter of the formatio reticularis is derived from the basal lamina and that of the nuclei pontis from the alar lamina by the active migration of cells from the rhombic lip. About the fourth month the pons is invaded by pontine and corticospinal fibres, becomes proportionately thicker, and takes on its adult appearance.

The region of the *isthmus rhombencephali* undergoes a series of changes which are very difficult to interpret. As a result, the greater part of the region apparently becomes taken up into the caudal end of the mid-brain, only the roof-plate, in which the anterior medullary velum is formed, and the dorsal parts of the alar laminae, which become invaded by the fibres of the superior cerebellar peduncles, remaining as recognisable derivatives in the adult. It should be noted that originally the decussation of the two fourth nerves is placed on the hind-brain side of the isthmus, but as the growth changes occur it is displaced in a headward direction until it reaches its adult position. Frazer† considers that these changes are also responsible (1) for the movement in the same direction of the nucleus of the fourth nerve, whereby it comes to lie in the mid-brain, and (2) for the position of the nucleus of the mesencephalic tract of the fifth nerve, which is also a derivative of the isthmus rhombencephali.

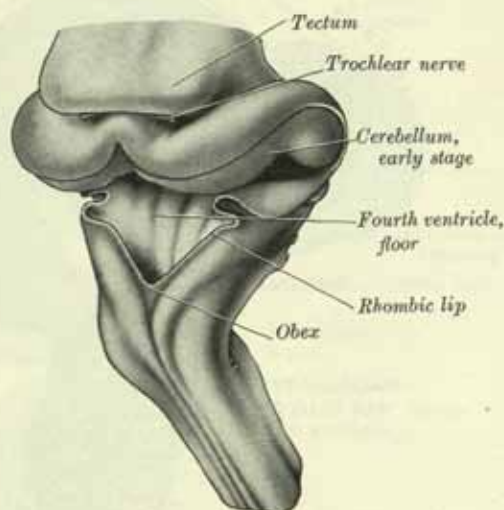
The **mesencephalon** or **mid-brain** (figs. 142, and 145 to 148) exists for a time as a thin-walled tube enclosing a cavity of some size, and is

* J. Ernest Frazer, *Manual of Embryology*, 1931.

† J. Ernest Frazer, *J. Anat.*, 63, 1928, and *loc. cit.*

separated from the fore-brain by a slight constriction and from the hind-brain by the isthmus rhombencephali. Its cavity becomes relatively reduced in diameter, and in the adult brain it forms the cerebral aqueduct. The basal laminae of the mid-brain increase in thickness to form the cerebral peduncles, which are at first of small size, but enlarge rapidly after the fourth month, when their fibre-tracts begin to appear in the marginal zone. The cells of the basal lamina give origin to the nucleus of the oculomotor nerve and to the grey matter of the tegmentum, while the nucleus of the trochlear nerve and the nucleus of the mesencephalic tract of the trigeminal nerve migrate headwards into the mid-brain owing to the developmental changes which occur in the isthmus rhombencephali. The cells of the dorsal part of the alar laminae proliferate and invade the roof-plate, which therefore becomes thickened and is later divided into *corpora bigemina* by a median groove. At its caudal end this groove becomes a median ridge, which persists in the adult as the frenulum veli. The corpora bigemina are later subdivided into the superior and

FIG. 144.—The dorsal aspect of the hind-brain of a human embryo about three months old. Viewed from behind and partly from the right side. (From a model by His.)



inferior colliculi by a transverse furrow. The red nucleus is clearly defined at the end of the third month whether from the neuroblasts of the alar or basal lamina. Its origin is uncertain.

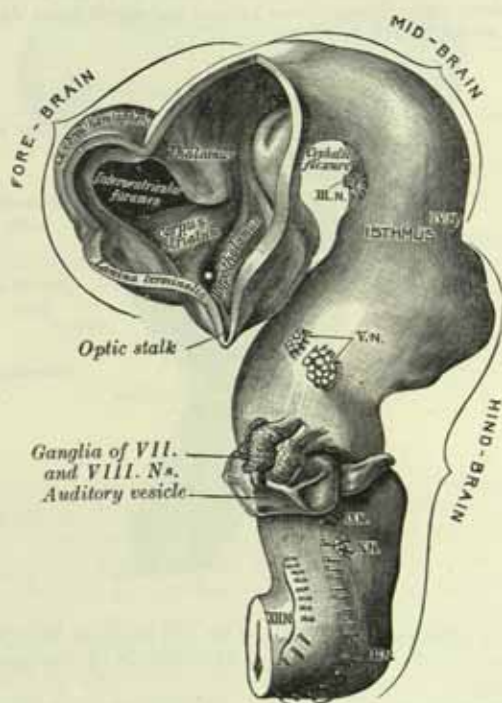
The prosencephalon or fore-brain.—A transverse section through the early fore-brain shows the same parts as are displayed in similar sections of the spinal medulla and medulla oblongata, viz. a pair of thick lateral walls connected by thin floor- and roof-plates. Moreover, each lateral wall is divided into a dorsal area and a ventral area separated internally by a furrow termed the *hypothalamic sulcus*. This sulcus ends anteriorly at the medial end of the optic stalk, and in the adult brain persists as a slight groove extending backwards from the interventricular foramen to the cerebral aqueduct.

At a very early period—before the closure of the anterior neuropore (p. 77)—two lateral diverticula, termed the *optic vesicles*, appear, one on each side of the fore-brain; for a time they communicate with the cavity of the fore-brain by relatively wide openings. The distal parts of the optic vesicles expand, while the proximal parts are reduced to tubular stalks, termed the *optic stalks*; their further development is given on pp. 146 to 149. The fore-brain then grows ventrally, and gives origin to two diverticula which rapidly expand to form two large pouches, one on each side. These diverticula subsequently form the cerebral hemispheres, and their contained cavities are the rudiments of the lateral ventricles; they communicate with the median part of the fore-brain cavity by relatively wide openings which ultimately form the interventricular foramina. The anterior part of the

roof-plate of the fore-brain consists of a thin sheet, termed the *lamina terminalis* (figs. 145 and 148) which stretches from the interventricular foramen to the recess at the base of the optic stalk. The anterior part of the fore-brain, including the rudiments of the cerebral hemispheres, is named the *telencephalon*, and the posterior portion the *diencephalon*; both contribute to the formation of the third ventricle, although the latter plays the predominant part.

The *diencephalon*.—The thalamus and the metathalamus are developed from the dorsal area of the lateral wall of the diencephalon. The *thalamus* (figs. 145 to 150) arises as a thickening which involves the anterior part of the dorsal area. Caudal to the thalamus the lateral and medial geniculate bodies, which constitute the *metathalamus*, are recognisable at first as surface depressions on the inner aspect and as elevations on the outer aspect of the lateral wall. As the

FIG. 145.—The brain of a human embryo, about 10·2 mm. long.
(From a model by His.)



thalami enlarge, they gradually narrow the wide interval between them into a slit-like cavity which forms the greater part of the third ventricle. After a time these medial surfaces come into contact and become adherent to each other over a variable area, the connexion constituting the *interthalamic adhesion*. The backward growth of the thalamus excludes the geniculate bodies from the lateral wall of the third ventricle.

At first the lateral aspect of the developing thalamus is separated from the medial aspect of the cerebral hemisphere by an extraneural cleft, but as growth proceeds the cleft becomes obliterated (fig. 149) and the thalamus comes into intimate relationship with the corpus striatum. Later, with the development of the projection fibres of the neopallium (p. 1062), the thalamus becomes related to the internal capsule, which intervenes between it and the lateral part of the corpus striatum [lentiform nucleus].

Below (ventral to) the hypothalamic sulcus the lateral wall of the diencephalon forms a large part of the hypothalamus.

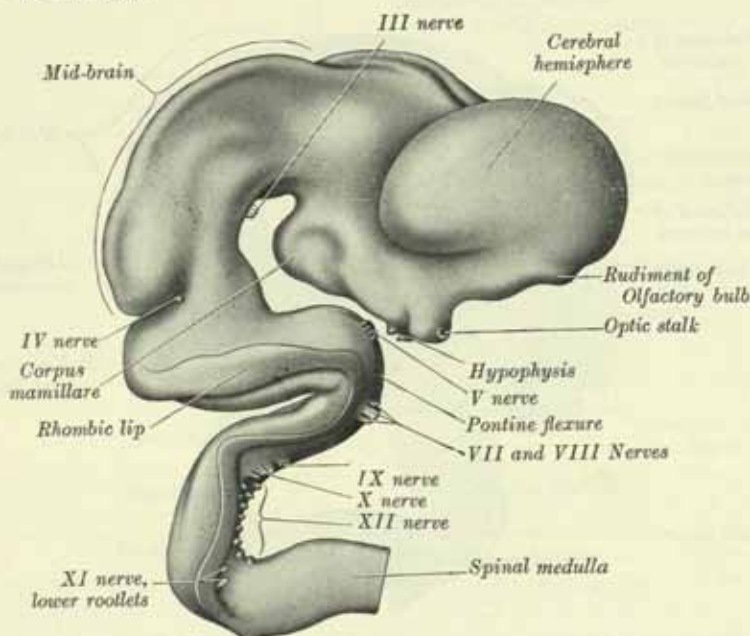
The *epithalamus*, which includes the pineal body, the posterior commissure and the trigonum habenulæ, develops in association with the caudal part of the roof-plate

and the adjoining portions of the lateral walls of the diencephalon. The *pineal body* arises as a hollow outgrowth from the roof-plate, immediately adjoining the mesencephalon. Its distal portion becomes solid, but its proximal portion, or stalk, remains hollow, containing the recessus pinealis of the third ventricle. In many reptiles the pineal outgrowth is double. The anterior outgrowth (parapineal organ) develops into the pineal or parietal eye (p. 1008) while the posterior outgrowth is glandular in character. *It is the posterior outgrowth which is homologous with the pineal body in man.* The anterior outgrowth also develops in the human embryo, but it very soon disappears entirely.

The *posterior commissure* is formed by fibres which invade the lower wall of the pineal recess from both sides.

The *nucleus habenulae*, which is the most important constituent of the *trigonum habenulae*, is developed in the lateral wall of the diencephalon and is at first in close

FIG. 146.—The right side of the brain of a human embryo, 13.6 mm. long. The roof of the hind-brain has been removed. (Drawn from a model by His.) Compare with Fig. 147.



relationship with the geniculate bodies, from which it becomes separated by the backward growth of the thalamus.

The roof-plate of the diencephalon, in front of the pineal body, remains thin and epithelial in character, and is subsequently invaginated by the chorioid plexuses of the third ventricle. Prior to the development of the corpus callosum and the fornix it lies at the bottom of the longitudinal fissure, which separates the two cerebral hemispheres from each other.

The floor of the diencephalon takes part in the formation of the *hypothalamus*, including the corpora mamillaria, the tuber cinereum and the infundibulum of the hypophysis.

The corpora mamillaria arise as a single thickening, which becomes divided by a median furrow during the third month. Anterior to the corpora mamillaria the tuber cinereum develops as a cellular proliferation which extends forwards as far as the infundibulum.

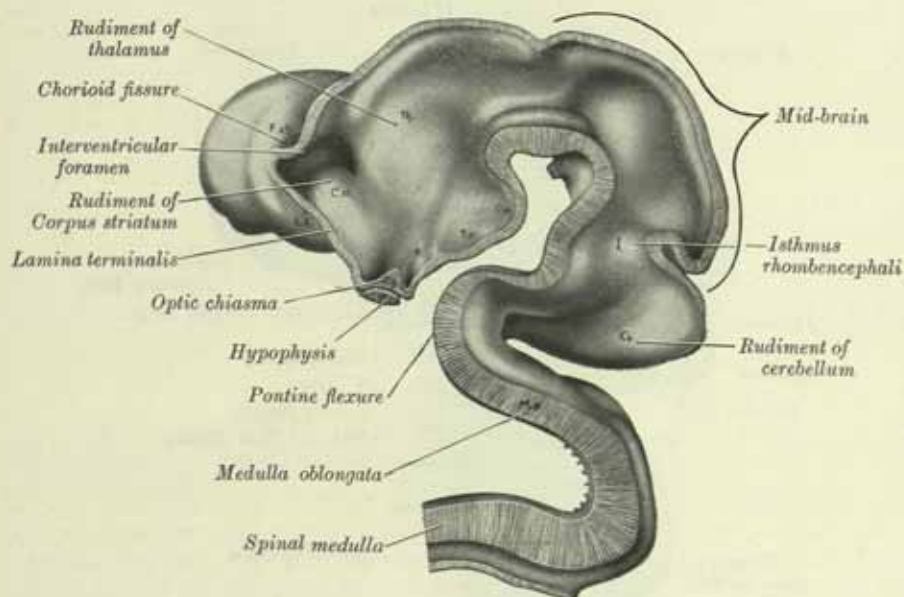
In front of the tuber cinereum the floor of the diencephalon gives origin to a wide-mouthed diverticulum, which grows towards the roof of the stomodæum and comes into relationship with the posterior aspect of Rathke's pouch (p. 185). These two diverticula, the one derived from the floor of the neural tube and the other

from the roof of the stomodæum, together form the *hypophysis* (fig. 199). The upper end of the neural outgrowth persists as the infundibular recess of the third ventricle.

The optic vesicles, which are described with the development of the eye (p. 146), are derived from the lateral wall of the prosencephalon before the telencephalon can be identified. They are usually regarded as derivatives of the diencephalon, and the optic chiasma indicates the boundary between the diencephalon and the telencephalon.

The *telencephalon* consists of a median portion and two lateral diverticula. The median portion forms the anterior part of the cavity of the third ventricle, and is closed below and in front by the *lamina terminalis*. The lateral diverticula consist of outward pouchings of the lateral walls of the prosencephalon, which may correspond to the alar laminae, although this is uncertain; the cavities represent the future lateral ventricles, and their walls the nervous matter of the cerebral hemispheres.

FIG. 147.—The brain of a human embryo, 13.6 mm. long. Medial surface of right half. The roof of the hind-brain has been removed. (From a model by His.)



The roof-plate of the median part of the telencephalon remains thin, and is continuous behind with the roof-plate of the diencephalon. In the floor-plate and the lateral walls of the prosencephalon ventral to the primitive interventricular foramen the anterior part of the *hypothalamus* is developed; this includes the optic chiasma and the optic recess. The optic chiasma is formed by the meeting and partial decussation of the optic nerves, and from it the optic tracts subsequently grow backwards to end in the diencephalon and mid-brain.

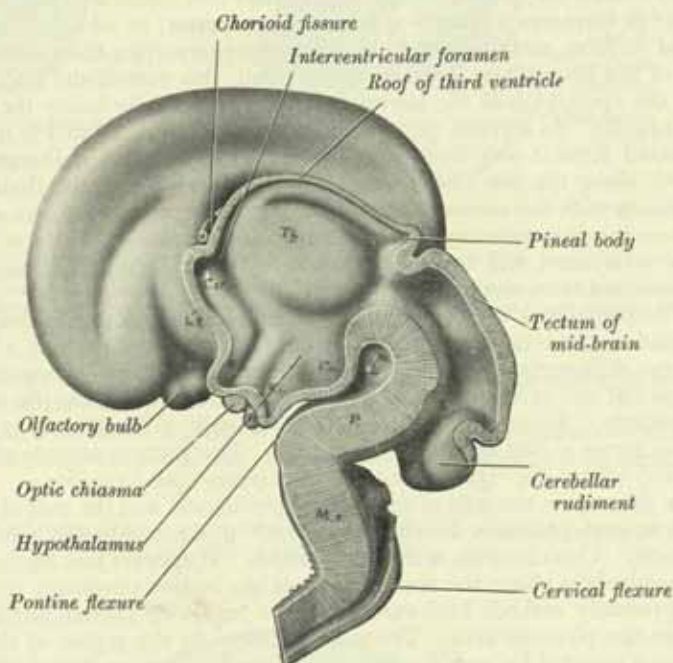
The cerebral hemispheres arise as diverticula of the lateral walls of the telencephalon, with which they remain in continuity around the upper, anterior and lower margins of the large, interventricular foramen. At the posterior margin of the foramen the wall of the hemisphere is continuous with the anterior part of the lateral wall of the diencephalon (fig. 145); as growth proceeds the hemisphere enlarges forwards, upwards and backwards and acquires an oval outline, with medial and superolateral walls and a floor. As a result the medial surfaces are separated from each other by a cleft which subsequently becomes the longitudinal fissure. At this stage the floor of the cleft is formed by the epithelial roof-plate of the telencephalon, which is directly continuous posteriorly with the epithelial roof-plate of the diencephalon (fig. 148).

The anterior pole of the oval hemisphere becomes the frontal pole, but, as the hemisphere enlarges, its original posterior pole is carried downwards and forwards,

apparently in association with the growth of the caudate nucleus, to form the temporal pole and a new posterior pole becomes defined, which will persist as the occipital pole of the adult brain. The enormous expansion of the cerebral hemispheres is characteristic of the mammalia and especially of man, and in their subsequent growth they hide, successively, the diencephalon, the mesencephalon and the cerebellum.

About the fifth week a longitudinal groove appears in the anteromedial part of the floor of the ventricle. This groove deepens and forms a hollow diverticulum connected to the hemisphere by a short stalk. The diverticulum becomes connected on its ventral or inferior surface to a ganglionic mass, the cells of which receive the afferent axons of the sensory cells of the olfactory plate. As the head increases in size the diverticulum grows forwards and, subsequently losing its cavity, becomes

FIG. 148.—Medial surface of the right half of the brain of a human embryo, about three months old. (Drawn from a model by His.)



Th. = thalamus. C.st. = corpus striatum. L.t. = lamina terminalis. C.m. = corpora mamillaria. M.o. = medulla oblongata. P. = pons.

converted into the solid olfactory bulb. The forward growth of the bulb is accompanied by the elongation of its stalk, which forms the olfactory tract, and the portion of the floor of the hemisphere to which the tract is attached constitutes the *piriform area*.

The pia mater which covers the epithelial roof of the third ventricle at this stage consists of loosely arranged mesenchyme. In the meshes of this tissue numerous blood-vessels develop, and on each side of the median plane these vessels subsequently invaginate the roof of the ventricle to form its *chorioid plexuses*. The lower part of the medial wall of the hemisphere, which immediately adjoins the epithelial roof of the interventricular foramen and the anterior extremity of the diencephalon, remains epithelial in character while elsewhere the walls of the hemisphere are thickening to form the *pallium*. This thin part of the medial wall of the hemisphere is invaginated by vascular tissue, continuous in front with the chorioid plexus of the third ventricle and constituting the chorioid plexus of the lateral ventricle. This invagination occurs along a line which arches upwards and backwards, parallel with the anterior and upper boundaries of the interventricular foramen, and the curved indentation of the ventricular wall is termed the *chorioid fissure* (fig. 148).

At first growth proceeds more actively in the floor and the adjoining part of the

lateral wall of the developing hemisphere, and an elevation is formed which encroaches on the cavity of the lateral ventricle. This elevation is the rudimentary *corpus striatum* (fig. 145), and it extends forwards to the floor of the interventricular foramen where it is separated from the developing anterior end of the thalamus only by a groove (fig. 147). Posteriorly the corpus striatum is, from the beginning, in close relationship to the temporal pole of the hemisphere and, when the occipital pole grows backwards and the general enlargement of the hemisphere carries the temporal pole downwards and forwards, it is continued from the floor of the central part of the ventricle into the roof of the inferior horn.

As the hemisphere enlarges the posterior part of its medial surface overlaps and hides the lateral surface of the diencephalon (thalamic part), being separated from it by a narrow cleft occupied by vascular connective tissue. At this stage (end of second month) a transverse section made behind the interventricular foramen passes successively through: (1) the developing thalamus (2) the narrow cleft just mentioned, (3) the thin medial wall of the hemisphere, and (4) the cavity of the lateral ventricle with the corpus striatum in its floor and lateral wall (fig. 149, A). As the thalamus increases in extent it acquires a superior, in addition to its medial and lateral surfaces, and the lateral part of its superior surface fuses with the thin medial wall of the hemisphere, so that, in the adult, this part of the thalamus is covered with the ependyma of the lateral ventricle immediately below the chorioid fissure (fig. 149, B). As a result the corpus striatum is approximated to the thalamus and separated from it only by a deep groove, which becomes obliterated by increased growth along the line of contact. The lateral aspect of the thalamus is now in continuity with the medial aspect of the corpus striatum, so that a secondary union between the diencephalon and the telencephalon is effected over a wide area, providing a satisfactory and convenient route for the subsequent passage of projection fibres to and from the pallium.

The pallial area which borders the interventricular foramen and lies outside the chorioid fissure constitutes the *archipallium*. It is the first part of the pallium to undergo differentiation, and at first it forms a continuous, almost circular strip on the medial and inferior aspects of the hemisphere, i.e. along the medial fringe of the pallium. Below and in front, where the stalk of the olfactory tract is attached, it constitutes a part of the *piriform area*. The portion outside the curve of the chorioid fissure (fig. 150) constitutes the *hippocampal formation*.

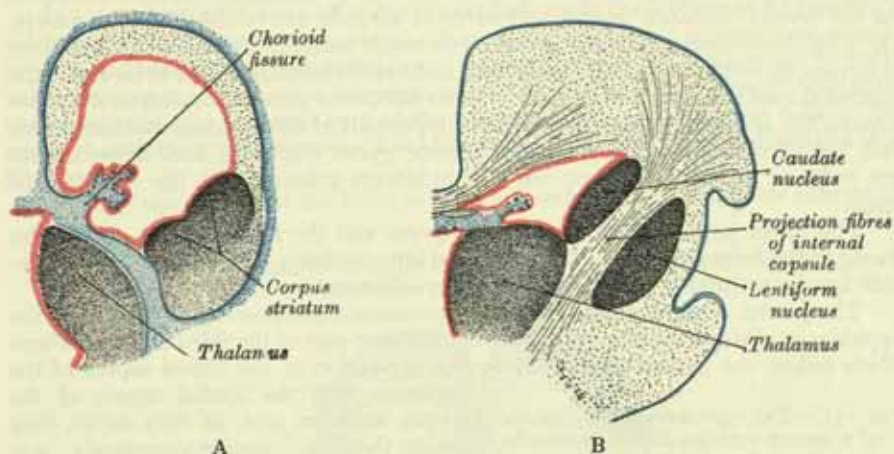
In this region the cells of the pallium proliferate, and the wall of the hemisphere thickens and produces an elevation which projects into the medial side of the ventricle. This elevation is the *hippocampus*. It appears first on the medial wall of the hemisphere above the area in front of the lamina terminalis [preterminal area] and gradually extends backwards into the region of the temporal pole, where it adjoins the piriform area. The marginal zone in the region of the hippocampus becomes invaded by nerve cells which form the *dentate gyrus*. This structure is practically co-extensive with the hippocampus, and, like it, extends from the preterminal area backwards above the chorioid fissure and follows its curve downwards and forwards towards the temporal pole, where it runs into the piriform area. A shallow surface depression, which has been termed the *hippocampal sulcus*, grooves the medial surface of the hemisphere in the region of the hippocampal formation, but it is not responsible for the elevation which the hippocampus forms in the interior of the ventricle.

The efferent fibres from the cells of the hippocampus collect along its medial edge and run forwards immediately above the chorioid fissure. Anteriorly they turn downwards and enter the lateral part of the lamina terminalis in order to gain the hypothalamus, where they end in the corpus mamillare. These efferent hippocampal fibres form the *fimbria* and the *fornix*.

The development of the commissures effects a very profound alteration on the medial wall of the hemisphere. At the time of their appearance the two hemispheres are connected to each other by the median part of the telencephalon. The roof-plate of this area remains epithelial and non-nervous, while its floor becomes invaded by the fibres of the optic nerves. These two routes are not available for the passage of commissural fibres passing from hemisphere to hemisphere across the median plane, and these fibres are therefore compelled to pass through the anterior wall of the interventricular foramen, i.e. the *lamina terminalis*. The first commissures to develop are those associated with the rhinencephalon and archipallium. Fibres

of the olfactory tracts cross in the ventral or lower part of the lamina terminalis and constitute the anterior part of the *anterior commissure*. In addition the two hippocampi become connected to each other by transverse fibres which cross

FIG. 149.—Diagrams illustrating transverse sections across the developing thalamus and cerebral hemisphere.



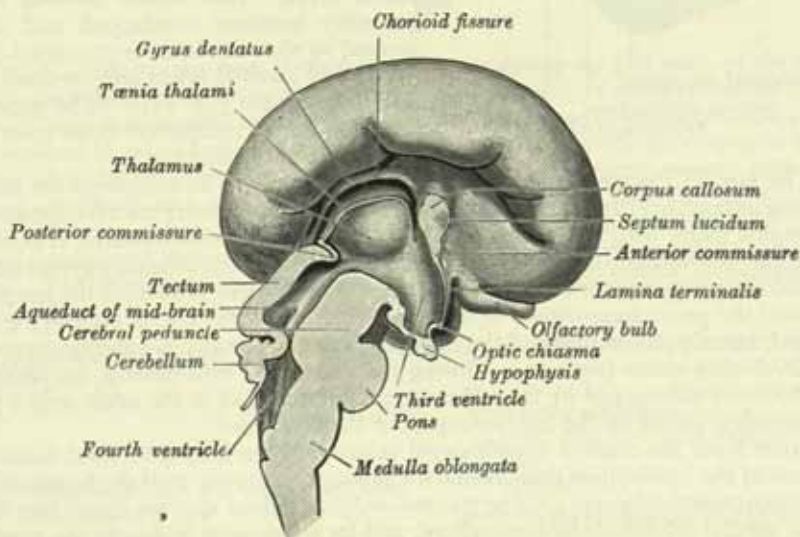
In *A* the lateral aspect of the thalamus is separated from the medial aspect of the hemisphere by an interval containing vascular mesenchyme.

In *B* this interval has disappeared; the expanded upper surface of the thalamus is covered by the ependyma of the lateral ventricle; and the approximation of the thalamus and the corpus striatum has provided a pathway for the projection fibres of the internal capsule.

from fornix to fornix in the upper part of the lamina terminalis and give origin to the *commissure of the fornix*.

The neopallial commissures develop later and follow the pathways already established by the commissures of the rhinencephalon. Fibres coming from the

FIG. 150.—The brain of a human embryo, four months old. Medial surface of left half. (Marchand.)



tentorial surface of the hemisphere join the anterior commissure and constitute its larger, posterior part. All the other commissural fibres of the neopallium associate themselves closely with the commissure of the fornix and lie on its dorsal surface.

These fibres increase enormously in number, and the bundle rapidly outgrows its neighbours to form the *corpus callosum* (fig. 150).

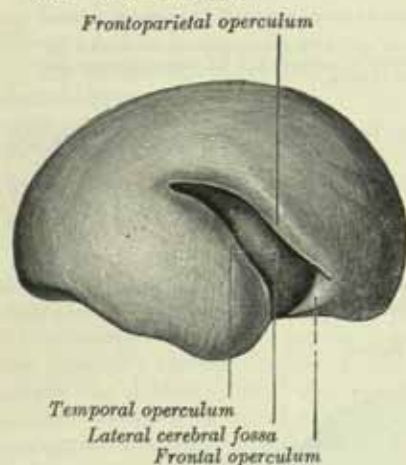
The first fibres of the corpus callosum lie within the limits of the lamina terminalis, but as the commissure increases in size it extends forwards and upwards and then backwards far beyond those limits. Since the fibres which enter the commissure from the temporal, parietal and occipital regions outnumber those coming from the frontal region, the principal enlargement occurs in a backward direction. As the corpus callosum grows backwards it extends above the chorioid fissure, carrying the commissure of the fornix on its under surface. In this way a new floor is formed for the longitudinal fissure, and additional structures come to lie above the epithelial roof of the third ventricle. In its backward growth the corpus callosum invades the area hitherto occupied by the upper part of the hippocampal formation, and the corresponding parts of the dentate gyrus (fig. 150) and hippocampus are reduced to mere vestiges, viz. the indusium griseum and the longitudinal striae.

The lower parts of both the dentate gyrus and the hippocampus persist, for owing to the forward growth of the temporal lobe the brain stem presents an impassable barrier to further growth of the corpus callosum.

The growth of the neopallium and its enormous expansion is associated with the appearance of the projection fibres during the latter part of the third month. These fibres follow the pathway provided by the apposition of the lateral aspect of the thalamus with the medial aspect of the corpus striatum, and, as they do so, they divide the latter, almost completely, into a lateral part [the lentiform nucleus], and a medial part [the caudate nucleus], these two nuclei remaining unseparated only in their antero-inferior portions.

At the end of the third month the lateral aspect of the cerebral hemisphere shows a slight depression above and in front of the temporal pole. This hollow corresponds to the site of the corpus striatum in the floor and lateral wall of the ventricle, and its presence is due to the more rapid growth of the adjoining pallial areas. This *lateral cerebral fossa* gradually becomes overlapped and submerged so that the fossa is converted into the *lateral cerebral sulcus* and its floor becomes the *insula* (fig. 151). The process, however, is not completed in its most anterior part until after birth.

FIG. 151.—The right cerebral hemisphere of a human embryo, about five months old. Lateral surface.



The growth changes in the temporal lobe which help to submerge the insula produce important changes in the rhinencephalon. The olfactory tract is continuous, on the one hand, with the medial olfactory gyrus, which turns upwards in front of the lamina terminalis, and, on the other hand, with the lateral olfactory gyrus, which is directly continuous with the piriform area. The forward growth of the temporal pole and the general expansion of the neopallium cause the lateral olfactory gyrus to bend laterally, the summit of the convexity lying at the antero-inferior corner of the developing insula (fig. 152). During the fourth and fifth months the piriform area becomes submerged by the adjoining neopallium, and in the adult only a part of it remains visible on the inferior aspect of the cerebrum.

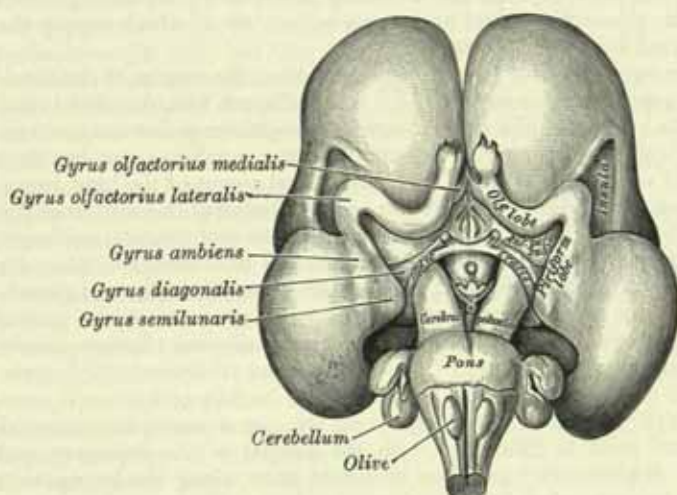
Apart from the shallow hippocampal sulcus and the lateral cerebral fossa the surfaces of the hemisphere remain smooth and uninterrupted until the beginning of the fourth month (fig. 151). The parieto-occipital sulcus appears about that time on the medial aspect of the hemisphere, and its appearance is due to the traction exerted by the splenial fibres of the corpus callosum. At about the same period the postcalcarine sulcus appears as a shallow groove extending forwards from the region of the occipital pole. It is a true infolding of the cortex and forms in the long axis of the striate area, producing at the same time an elevation, named the *calcar avis*, on the medial wall of the posterior horn of the ventricle.

During the fifth month the sulcus cinguli appears on the medial aspect of the hemisphere, but it is not until the sixth month that sulci appear on the inferior and superolateral aspects. The central, precentral and postcentral sulci appear each in two parts, upper and lower, which usually coalesce shortly afterwards, although they may remain ununited. The superior and inferior frontal, the intraparietal, occipital, temporal and collateral sulci make their appearance during the same period, and by the end of the seventh month all the important sulci can be recognised.

If a section through the wall of the hemisphere about the sixth week be examined microscopically it is seen to consist of a thin marginal layer, an intermediate mantle layer and an inner, thick ependymal layer. It therefore resembles the spinal medulla at the same stage. Thereafter, however, neuroblasts from the ependymal and mantle layers migrate into the deep part of the marginal layer and form the cells of the cerebral cortex in that situation. The differentiation of the cortex is described in a later section.

At birth the volume of the brain is approximately 25 per cent. of its volume in

FIG. 152.—The brain of an embryo at the beginning of the fourth month.
Inferior surface. (Kollmann.)



adult life. *The greater part of the increase occurs during the first year, at the end of which the volume of the brain has increased to 75 per cent. of its adult volume.* The growth can be accounted for partly by increase in the size of the nerve-cells and of the cerebral blood-vessels, but it is the acquisition of their medullated sheaths by the nerve fibres which is principally responsible for it. The great sensory pathways, visual, auditory and somatic, become medullated first, and the motor fibres later. During the second year and subsequent years growth proceeds much more slowly, and the brain attains its adult size by the seventeenth or eighteenth year. The continued growth is connected with the continued medullation of nerve-fibres.

A summary of the parts derived from the cerebral vesicles is given in the following table:—

Rhombencephalon or hind-brain	1. Myelencephalon	{ Medulla oblongata. Lower part of fourth ventricle. Pons.
	2. Metencephalon	{ Cerebellum. Middle part of fourth ventricle. Anterior medullary velum.
	3. Isthmus rhombencephali	{ Superior cerebellar peduncles. Upper part of fourth ventricle. Cerebral peduncles.
Mesencephalon or mid-brain		{ Tectum (lamina quadrigemina). Aqueduct.

Prosencephalon or fore-brain	{	1. Diencephalon	{	Thalamus.
				Metathalamus.
	{	Epithalamus.		
		Posterior part of hypothalamus.		
		Posterior part of third ventricle.		
		Anterior part of third ventricle.		
		Anterior part of hypothalamus.		
		Cerebral hemispheres.		
		Lateral ventricles.		
		Interventricular foramen.		

The cranial nerves.—With the exception of the olfactory and optic nerves, which will be considered separately, the cranial nerves are developed in a similar manner to the spinal nerves.

The fibres of the motor cranial nerves are the axons of cells in the basal lamina of the mid- and hind-brains, and pass outwards to their distribution, but whereas the motor fibres of the spinal nerves form one series, those of the cranial nerves form two, according as they are derived from the medial or lateral parts of the basal lamina. The first series comprises the oculomotor, trochlear, abducent and hypoglossal nerves; the second comprises the accessory nerve, and the motor parts of the trigeminal, facial, glossopharyngeal and vagus nerves, all of which supply the striped muscles derived from the visceral arches.

As the lips of the neural groove fuse with each other in the region of the hind-brain and midbrain, a *neural crest* is formed and it is homologous with the neural crest of the spinal medulla. The ganglia of the vagus, glossopharyngeal, stato-acoustic (in part), facial and trigeminal nerves are derived from the ganglion-crest, but they migrate ventrally and soon come to lie on the ventrolateral aspect of the hind-brain. The stato-acoustic nerve ganglion is believed to receive contributions also from the wall of the auditory vesicle. There is much descriptive and experimental evidence, mainly from lower vertebrates, that overlying ectodermal thickenings or placodes contribute to the ganglia of the trigeminal, facial, stato-acoustic, vagus and glossopharyngeal nerves. It is claimed that these contributions give rise to the special somatic afferent (acoustic and lateral line) and the special visceral afferent (chiefly gustatory) components of these nerves. The development of these cranial nerve ganglia and the rôle of the ectodermal placodes in the human embryo still need clarifying (see p. 117). Caudal to the ganglion of the vagus nerve the occipital portion of the neural crest is concerned with the ganglia of the accessory and hypoglossal nerves. Rudimentary ganglion cells may occur along the hypoglossal nerve in the human embryo; they undergo regression later. The central processes of the cells of these ganglia form the sensory roots of these nerves and enter the alar lamina of the hind-brain, while their peripheral processes form the nerves themselves. The incoming fibres from the facial, glossopharyngeal and vagus nerves collect to form an oval bundle, termed the *tractus solitarius* (p. 133), on the lateral aspect of the myelencephalon. This bundle is the homologue of the oval bundle of the spinal medulla.

The autonomic system.—The ganglion cells of the *sympathetic system* are derived from the neural crest through the medium of the primitive spinal ganglia (p. 128). Certain of the cells in the ventral parts of these ganglia migrate towards the sides of the aorta, where they subsequently form the ganglia of the sympathetic trunks. Others migrate still further and eventually form the subsidiary sympathetic ganglia (fig. 153). The original migration is limited to the thoracic and upper lumbar regions. Thereafter the chain grows headwards and tailwards until the whole trunk is laid down. The view has been advanced that the sympathetic ganglion cells are, at least in part, derived from cells which migrate from the basal lamina along the ventral nerve roots. The results of destruction of the neural crest in chick embryos and of excision of the neural crest and portions of the neural tube in frog embryos have been somewhat contradictory in the hands of different investigators. On the whole the balance of the evidence favours the earlier view.

The ganglion cells of the cranial part of the *parasympathetic system* are probably derived from the ganglion crest through the medium of the primitive ganglia of the third, fifth, seventh, ninth and tenth cranial nerves. The ciliary ganglion is formed by cells which migrate from the trigeminal ganglion along the ophthalmic nerve, but it almost certainly is reinforced by cells migrating from the nucleus of the oculomotor

nerve. The sphenopalatine ganglion receives contributions from the ganglia of the fifth and seventh nerves; the otic from that of the ninth; and the submandibular from that of the seventh cranial nerve.

The meninges.—The dura mater, which is always intimately related to skeletal structures, is mesodermal in origin. The arachnoid and the pia mater, however, are more closely related to the brain and the spinal medulla, and experimental work* is strongly suggestive of their derivation from the neural crest. Portions of the neural tube transplanted without the adjoining portion of the neural crest develop a covering of dura mater, but no fluid spaces, such as the subarachnoid space, are formed and no chorioid plexus develops. If, however, the adjoining part of the neural crest is included in the graft, the transplant develops coverings of arachnoid and pia mater and subarachnoid and subdural spaces in addition to an outer covering of dura mater.

The chromaffin organs.—

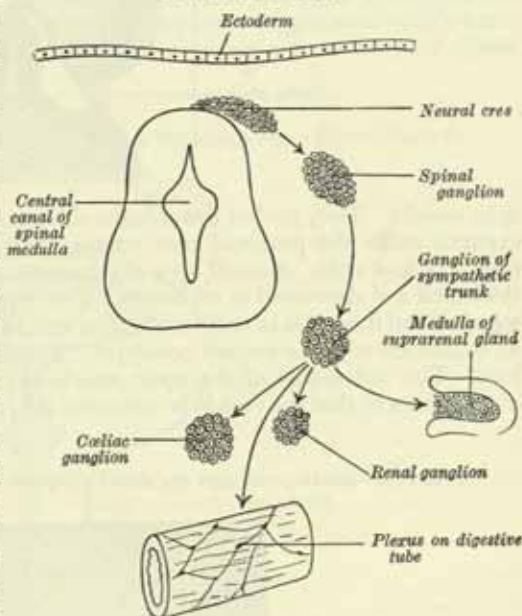
The tissue from which the sympathetic ganglia are formed is at first a syncytium of cells termed *sympathochromaffin cells*, but later two varieties of cells—small and large—are differentiated from it; the small cells (sympathoblasts) are transformed into the sympathetic nerve-cells, the large become chromaffin cells, and, separating from the others, accumulate to form the chromaffin organs. In the trunk of the sympathetic the chromaffin bodies are situated in depressions in the ganglia. In connexion with certain, but not all, of the secondary plexuses of the sympathetic system chromaffin organs are found; the largest members of this series are the *para-aortic bodies*, which lie along the sides of the abdominal aorta between the superior mesenteric and common iliac arteries; these bodies are commonly termed *paraganglia*. After birth the aortic bodies and the chromaffin bodies of the sympathetic ganglia degenerate and can no longer be isolated by gross dissection, but chromaffin tissue can be recognised with the microscope in the sites which they originally occupied.

The suprarenal glands.—Each suprarenal gland consists of a cortical portion derived from the cœlomic mesothelium and a medullary portion originally composed of sympathochromaffin tissue. The cortical portion is first recognisable about the beginning of the sixth week as a series of buds from the cœlomic cells at the root of the mesentery. These buds become separated from the cœlomic mesothelium and form a suprarenal ridge projecting into the cœlom between the mesonephros and the root of the mesentery. They form the *fœtal cortex*, which undergoes involution soon after birth. A second ingrowth from the cœlomic mesothelium forms a layer of small cells over the surface of the ridge, and eventually persists as the definitive cortex. In the eighth week cells from the neighbouring masses of sympathochromaffin tissue migrate into the fœtal cortex along the line of its central vein and form the medullary portion of the gland.

The nose.—The development of the nose has already been considered (pp. 111 to 115).

The *olfactory nerves* are developed from the cells which line the olfactory pits; these cells undergo proliferation and give rise to what are termed the *olfactory cells* of the nose. Their central processes are usually described as growing into the over-

FIG. 153.—Diagram showing the chief derivatives of the neural crest.



* S. C. Harvey and H. S. Burr, *Arch. of Neurol. Psychiat.* 15, 1926. This view has recently been contested by E. C. Sensenig. *Contr. Embryol.*, Carneg. Instn., 34, 1951.

lying olfactory bulb and forming the olfactory nerves. It has, however, been shown that the olfactory cells are from the first connected with the brain by a bridge of protoplasm which is never severed, and that the olfactory nerve fibres are developed in this bridge.*

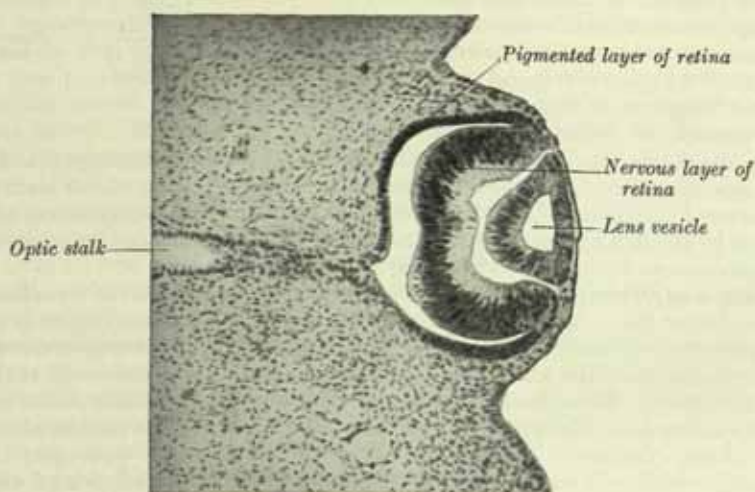
The eyes.—The rudiments of the eyes appear as a pair of hollow diverticula from the lateral aspects of the fore-brain. These diverticula are visible some time before the closure of the anterior neuropore; after its closure they are known as the

FIG. 154.—Section through the optic vesicle of a mole embryo, 3.5 mm. long.



optic vesicles. They project towards the sides of the head, and the distal part of each expands while the proximal part remains narrow and constitutes the *optic stalk* (figs. 154 and 156). A small area of ectoderm overlying the optic vesicle becomes thickened and depressed in its centre. The depression deepens and its edges come together and fuse so as to enclose a hollow vesicle (figs. 154 and 155) which soon loses its connexion with the surface ectoderm. This is the *lens vesicle*, or rudiment of the lens. The outer wall of the optic vesicle increases in thickness and undergoes invagination so that the vesicle is converted into a cup, termed the *optic cup*, consist-

FIG. 155.—Section through the developing eye of a mole embryo, 6.5 mm. long.



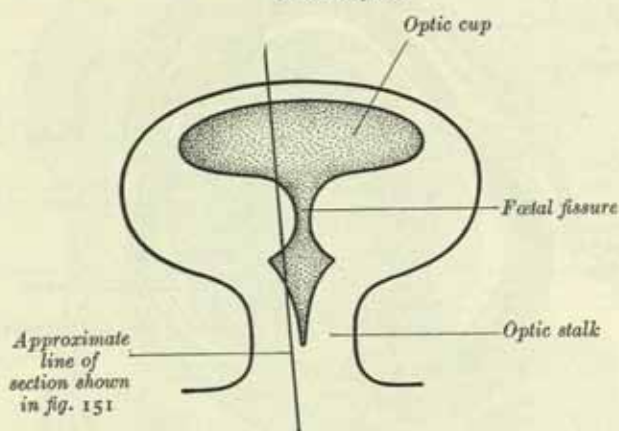
ing of two strata of cells (fig. 155). These two strata are continuous with each other at the cup-margin, which grows forwards at the end of the third month overlapping the front of the lens and reaching as far as the future aperture of the pupil. The invagination is not limited to the outer wall of the vesicle, but involves also its caudal surface and extends in the form of a groove for some distance along the optic stalk. Thus, for a time, a wide gap, termed the *fetal* or *chorioidal fissure*, exists in the caudal part of the cup (fig. 156). Through the groove and fissure mesenchyme extends into the optic stalk and cup, carrying the hyaloid artery with it; as growth

* G. Elliot Smith, *Anat. Anz.*, Band 33, 1908, and Frances M. Ballantyne. *Trans. Roy. Soc. Edin.*, 53, 1925.

proceeds, the edges of the fissure become approximated and they close during the seventh week, including the artery in the distal portion of the stalk. Failure of the fetal fissure to close is a very rare anomaly and always implies a corresponding deficiency in the chorioid and the iris (congenital coloboma). It must be noted, however, that localised deficiencies of the chorioid and iris may occur quite independently, and in such cases the retina is normal.*

The retina is developed from the optic cup. The outer stratum of the cup persists as a single layer of cells, which assume a columnar shape, acquire pigment, and form the pigmented layer of the retina, the pigment first appearing in the cells near the edge of the cup. The cells of the inner stratum proliferate and form a layer of considerable thickness from which the nervous elements and the sustentacular fibres of the retina, together with a portion of the vitreous body, are developed. In the portion of the cup which overlaps the lens the inner stratum is not differentiated into nervous elements, but persists as a layer of columnar cells which, together with the corresponding part of the pigmented layer, form the *pars ciliaris* and *pars iridica retinae*.

FIG. 156.—Diagram of the optic cup at the end of the fifth week. Viewed from the caudal aspect.



The cells of the inner layer of the cup proliferate and form an outer nuclear zone and an inner marginal zone, devoid of nuclei. At 12 mm. the cells of the nuclear zone invade the marginal zone, and at 17 mm. the nervous stratum of the retina consists of inner and outer neuroblastic layers. The inner neuroblastic layer gives origin to the ganglion cells, the amacrine cells and the nuclei of the sustentacular fibres; the outer neuroblastic layer gives origin to the horizontal cells and the nuclei of the rod- and cone-bipolar cells, which first appear in the central part of the retina. By the eighth month all the layers of the retina can be identified.

The deepest part of the fetal fissure is at the centre of the floor of the optic cup. In this situation, which later is the site of the optic disc, the inner (neural) cell layer of the cup is continuous with the corresponding invaginated cell layer of the optic stalk and, as a result, the developing nerve fibres of the ganglion cells can pass directly into the wall of the stalk to convert it into the optic nerve. The fibres of the optic nerve begin to acquire their medullary sheaths shortly before birth, but the process is not completed until the second week after birth.† The optic chiasma is formed by the meeting and partial decussation of the fibres of the two optic nerves, and it marks the junction of the telencephalon with the diencephalon in the floor of the third ventricle. Behind the chiasma the fibres are continued backwards as the optic tracts to the lateral geniculate bodies.

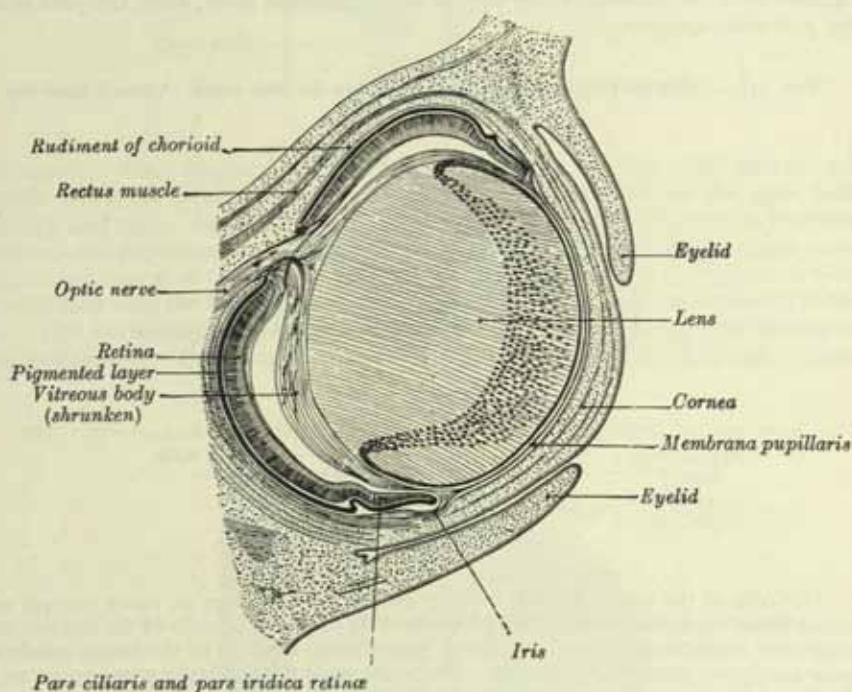
The lens is developed from the lens vesicle, which recedes within the margin of the cup and becomes separated from the overlying ectoderm by mesenchyme. The cells forming the posterior wall of the vesicle lengthen and are converted into the lens-fibres, which grow into and fill the cavity of the vesicle (figs. 157 and 158). The cells forming the anterior wall retain their cellular character, and form the epithelium on

* Ida C. Mann, *The Development of the Human Eye*, London, 1928.

† M. F. Lucas Keene and E. E. Hewer, *J. Anat.*, 66, 1931.

the anterior surface of the fully developed lens; at the equator of the lens the gradual transition of the cells into lens-fibres can be seen. By the second month the lens is invested by a vascular mesenchymal capsule termed the *capsula vasculosa lentis*, the ventral part of which, covering the lens, is named the *pupillary membrane*; the blood-vessels supplying the dorsal part of this capsule are derived from the hyaloid artery; those for the ventral part from the anterior ciliary arteries. By the sixth month all the vessels of the capsule are atrophied except the hyaloid artery, which becomes occluded during the eighth month of intrauterine life. Prior to this, during the fourth month, the hyaloid artery gives off retinal branches, and its proximal part persists in the adult as the central artery of the retina. The hyaloid canal, which gives passage to the artery through the vitreous, persists after the vessel has become

FIG. 157.—A section through the eye of a rabbit embryo, about eighteen days old. $\times 30$. (Kölliker.)



occluded. In the newly-born child it extends more or less horizontally from the optic disc to the posterior aspect of the lens but, when the adult eye is examined with the slit-lamp, it can be seen to follow a wavy, curved course, sagging downwards as it passes forwards to the lens.* With the loss of its blood-vessels the *capsula vasculosa lentis* disappears, but sometimes the pupillary membrane persists at birth, giving rise to the condition termed *congenital atresia of the pupil*.

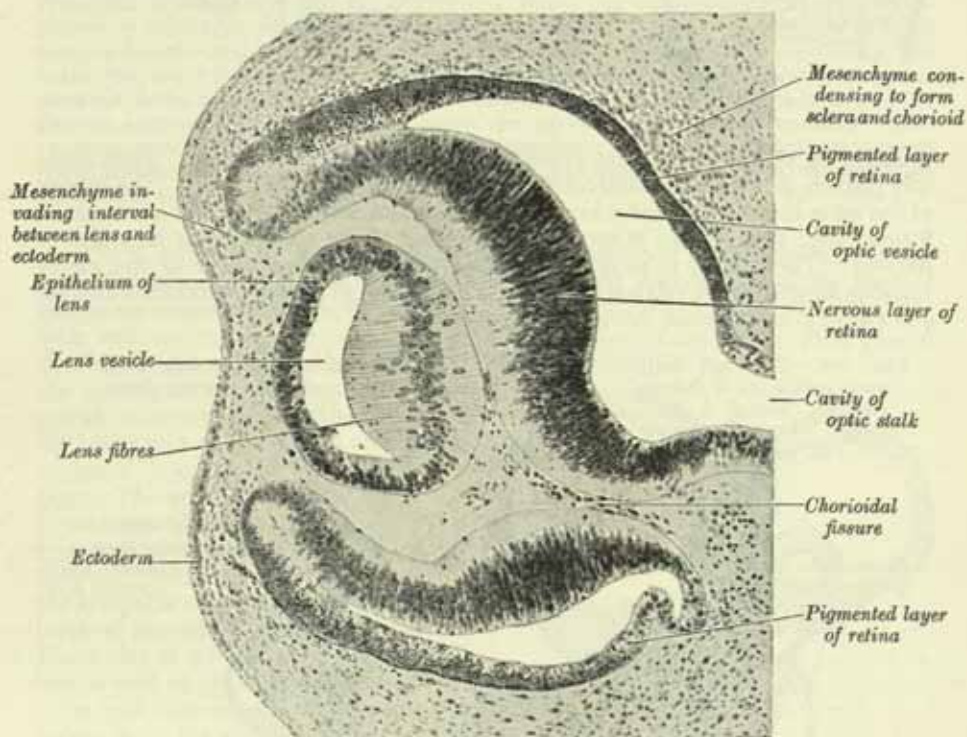
The vitreous body is developed between the lens and the optic cup. The lens rudiment and the optic vesicle are at first in contact with each other, but after the closure of the lens vesicle and the formation of the optic cup the former is withdrawn from the retinal layer of the cup; the two, however, remain connected by a network of delicate protoplasmic processes. This network, derived partly from the cells of the lens and partly from those of the retinal layer of the cup, constitutes the primitive vitreous body. At first these protoplasmic processes spring from the whole of the retinal layer of the cup, but later are limited to the ciliary region, where by a process of condensation they appear to form the *zonula ciliaris*. The mesenchyme which enters the cup through the chorioidal fissure and around the equator of the lens becomes intimately united with this reticular tissue, and contributes to the formation of the vitreous body, which is therefore derived partly from the ectoderm and partly from the mesoderm.

* Ida C. Mann, *J. Anat.*, 62, 1927.

The aqueous chamber of the eye appears as a cleft in that part of the mesenchyme which intervenes between the lens and the ectoderm. The layer of mesenchyme ventral to the cleft forms the substantia propria of the cornea, that dorsal to the cleft the mesenchymal stroma of the iris and the pupillary membrane. When the pupillary membrane disappears the anterior and posterior chambers of the eye communicate with each other.

The sclera and chorioid are derived from the mesenchyme surrounding the optic cup, and the anterior part of the chorioid is modified to form the ciliary body and ciliary processes. The fibres of the ciliaris muscle are derived from the mesoderm, but those of the sphincter and dilatator pupillæ are of ectodermal origin, being developed from the cells of the pupillary part of the optic cup.

FIG. 158.—A section through the developing eye of a human embryo, 13.2 mm. long. (G. L. Streeter, *Contr. Embryol.*, Carneg. Instrn., 32, 1948.) Compare with Fig. 156.



The eyelids are formed as small cutaneous folds (fig. 157). About the middle of the third month their edges come together and unite over the cornea; they remain united until about the end of the sixth month.

The epithelium of the alveoli and ducts of the lacrimal gland arise as a series of tubular buds from the ectoderm of the superior conjunctival fornix; these buds are arranged in two groups, one forming the gland proper, and the other its palpebral process. The lacrimal sac and nasolacrimal duct are derived from a thickening of the ectoderm in the *naso-optic furrow* between the lateral nasal and maxillary processes (p. 111). This thickening forms a solid cord of cells which sinks into the mesenchyme; during the third month the central cells of the cord break down, and a lumen is acquired. In this way the nasolacrimal duct is established. The lacrimal canaliculi arise as buds from the upper part of the cord of cells and secondarily establish openings (*puncta lacrimalia*) on the margins of the lids; the inferior canaliculus cuts off a small part of the lower eyelid to form the *caruncula lacrimalis* (Ask). The epithelium of the cornea and conjunctiva is of ectodermal origin, as are also the eyelashes and the lining cells of the tarsal and other glands which open on the margins of the eyelids.

The ears.—The rudiments of the internal ears appear shortly after those of the eyes, as two patches of thickened, surface epithelium, termed the *auditory placodes*, which are situated in the region of the hind-brain. These patches, though sur-

FIG. 159.—A section through the hind-brain and auditory pits of a human embryo, about twenty-four days old. (Kollmann.)

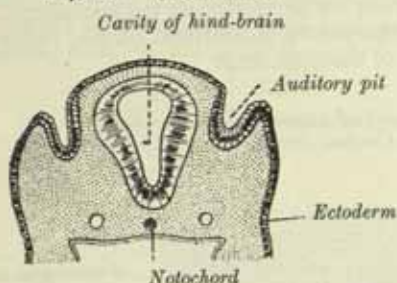
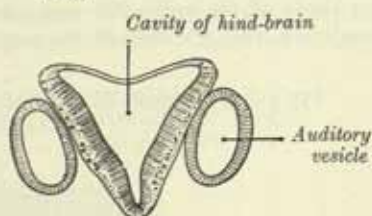


FIG. 160.—A section through the hind-brain and auditory vesicles of an embryo more advanced than that of fig. 159. (After His.)



rounded by skin ectoderm, are probably neurectodermal in character. Each auditory placode is invaginated and converted into an *auditory pit* (fig. 159). The mouth of the pit is then closed, and a vesicle, termed the *auditory (otic) vesicle* or *otocyst*, is formed (fig. 160); from it the epithelial lining of the membranous labyrinth is derived. The vesicle is piriform in shape and is the forerunner of the membranous labyrinth. A vertical infolding of its wall progressively marks off a tubular

FIG. 161.—The left auditory vesicle of a human embryo, about 6 mm. long. Lateral aspect. (W. His, jun.)

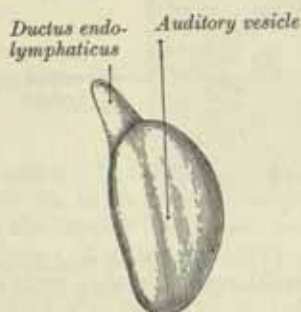
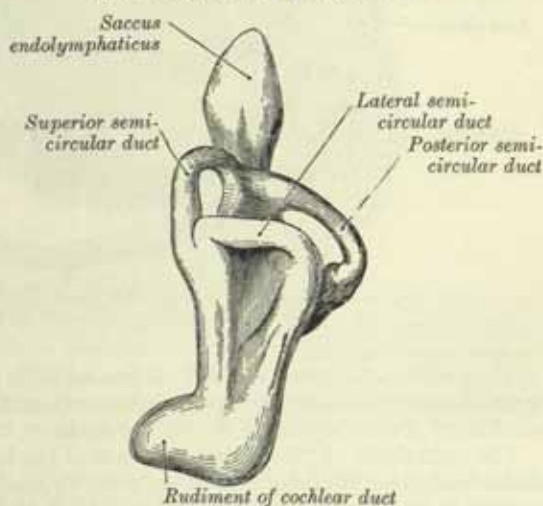


FIG. 162.—The left auditory vesicle of a human embryo, about 15 mm. long. Lateral aspect. (W. His, jun.)



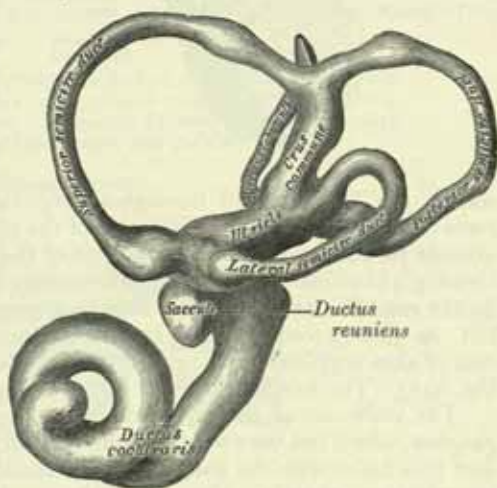
diverticulum on the medial side (fig. 161). This diverticulum differentiates into the ductus and saccus endolymphaticus, and it communicates with the remainder of the vesicle, which is termed the *utricleosaccular chamber* and is placed laterally. From the dorsal part of this chamber three compressed diverticula appear as disc-like evaginations; the central parts of the walls of the discs coalesce and disappear, while the peripheral portions of the discs persist to form the *semicircular ducts*; the superior duct is the first, and the lateral the last, to be completed (fig. 162). From the ventral part of the utricleo-saccular chamber rises a medially directed evagination which becomes coiled and forms the *cochlear duct*, the proximal extremity of which is subsequently constricted to form the *ductus reuniens*. The central part of the

chamber now represents the membranous vestibule and is subdivided into a smaller ventral part, the saccule, and a larger dorsal part, the utricle, mainly by a horizontal infolding, which extends deeply, from the lateral wall, towards the opening of the ductus endolymphaticus leaving only a narrow communication, the utriculosaccular duct, between the subdivisions (fig. 163). This duct becomes acutely bent on itself. During this period the membranous labyrinth undergoes a rotation so that the long axis, originally vertical, becomes more or less horizontal.*

The mesenchyme surrounding the various parts of the epithelial labyrinth is converted into a cartilaginous ear-capsule, and this is finally ossified to form the bony labyrinth of the internal ear. For a time the cartilaginous ear capsule is incomplete, and the cochlear, vestibular, and facial ganglia are situated in the gap between its canalicular and cochlear parts. These ganglia are soon covered by an outgrowth of cartilage and at the same time the facial nerve is bridged by a growth of cartilage from the cochlear to the canalicular part of the capsule. In the embryonic connective tissue between the cartilaginous capsule and the epithelial wall of the labyrinth the perilymphatic spaces are developed. Streeter † states that the rudiment of the *periotic cistern* or vestibular perilymphatic space can be seen in an embryo of from 30 to 40 mm. in length, in the reticulum between the saccule and the fenestra vestibuli. The scala tympani is next developed, and begins opposite the fenestra cochleæ; the scala vestibuli is the last to appear. The two scalæ gradually extend along each side of the ductus cochlearis, and when they reach the tip of the ductus an opening which represents the helicotrema is developed between them. The modiolus and the osseous spiral lamina of the cochlea are not preformed in cartilage but are ossified directly from connective tissue.

The auditory tube and tympanic cavity are developed from a recess, termed the *tubotympanic recess*,‡ between the first and third visceral arches, the floor of the recess consisting of the second arch and its limiting grooves. By the forward growth of the third arch the inner part of the recess is narrowed to form the tubal region, and the inner part of the second arch is excluded from this portion of the floor. The outer part of the recess is subsequently developed into the tympanic cavity, and the floor of this part forms the lateral wall of the tympanic cavity up to about the level of the chorda tympani nerve. From this it will be seen that the lateral wall of the tympanic cavity "has both first and second arch elements in it, the share taken by the first arch being limited to the part in front of the handle of the malleus. The area of the second arch includes the outer wall behind this, and turns on to the back wall to take in the tympanohyal region." The tubotympanic recess is placed at first on the infero-lateral aspect of the cartilaginous auditory capsule, but as the latter enlarges the relations become altered and the tympanic cavity comes to lie antero-lateral to the capsule. A cartilaginous process grows out from the lateral part of the capsule to form the tegmen tympani, and it curves caudally to form the lateral wall of the auditory tube. In this way, subsequent to the process of ossification, the tympanic cavity and the proximal part of the auditory tube become included in the petrous part of the temporal bone. During the sixth or seventh month the tympanic antrum appears as a dorsal expansion of the tympanic cavity.

FIG. 163.—The left membranous labyrinth of a human embryo, 30 mm. long. (From a model by W. His, jun.)



* This account differs in detail from that of Streeter and is based on the work of T. H. Bast, and B. J. Anson, *The Temporal Bone and the Ear*, Illinois, 1949.

† George L. Streeter, *Amer. J. Anat.*, 21, 1917.

‡ J. Ernest Frazer, *J. Anat. and Physiol.*, 48, 1914.

The opinion generally held as to the development of the ossicles of the middle ear is that the *incus* and *malleus* are derived from the dorsal end of the mandibular (Meckel's) cartilage (fig. 129), the incus representing the quadrate bone of birds and reptiles. The *stapes* is developed mainly from the dorsal end of the cartilage of the second or hyoid arch, and first appears as a ring (annulus stapedis) encircling the small stapedial artery (p. 169).

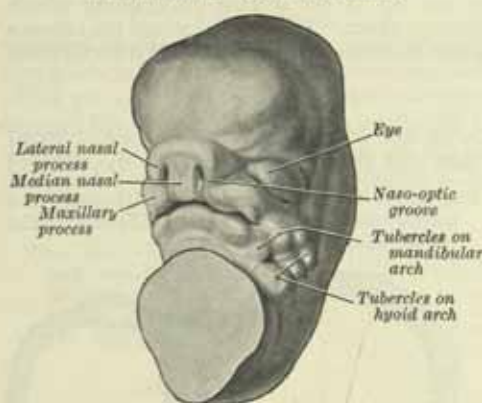
At first the ossicles are embedded in the mesenchymal roof of the tympanic cavity, and their extraneous origin is indicated in the adult by the covering which they receive from its mucous lining.

The external auditory meatus is developed from the dorsal end of the hyomandibular or first visceral cleft. Close to its upper extremity this groove extends inwards as a funnel-shaped tube (primary meatus) from which the cartilaginous portion and a small part of the roof of the osseous portion of the meatus are developed. From the funnel-shaped tube a solid epidermal plug extends inwards along the floor of the tubotympanic recess; by the breaking down of the central cells of this plug the inner part of the meatus (secondary meatus) is produced, while the deepest cells of the ectodermal plug form the epidermal stratum of the tympanic

membrane. The fibrous stratum of the tympanic membrane is formed from the mesenchyme which extends between the meatal plate and the entoderm of the floor of the tubotympanic recess.

The development of the auricle is preceded by the appearance of six tubercles which form round the margins of the dorsal portion of the hyomandibular cleft. Of the six, three are situated on the caudal edge of the mandibular arch and three on the adjoining cephalic edge of the hyoid arch (fig. 164). These tubercles appear at the 4 mm. stage, but they tend to become obscured as development proceeds and of those on the mandibular arch only the most ventral, which subsequently forms the

FIG. 164.—An early stage in the development of the auricle. (G. L. Streeter.)



tragus, can be identified throughout (fig. 121). The remainder of the auricle owes its development to proliferation of the mesenchyme of the hyoid arch,* which extends forwards round the dorsal end of the remains of the hyomandibular cleft, forming a keel-like elevation—the forerunner of the helix. The contribution made by the mandibular arch to the auricle is greatest at the end of the second month but, as growth continues, it becomes relatively reduced so that eventually the area of skin supplied by the mandibular nerve extends very little above the tragus (fig. 940). The lobule is the last part of the auricle to develop.

The rudiment of the eighth nerve appears in the fourth week as the *auditory ganglion*, which lies between the auditory vesicle and the wall of the hind-brain. At first it is fused with the ganglion of the facial nerve (acousticofacial ganglion) but later the two separate. The cells of the ganglion are mainly derived from those of the neural crest, but probably some come from the neur ectoderm of the auditory vesicle. The auditory ganglion divides into a vestibular and a cochlear part, each associated with the corresponding division of the eighth nerve. The cells of these ganglia retain their bipolar shape throughout life, each sending a proximal fibre into the brain, and a peripheral fibre to the internal ear.

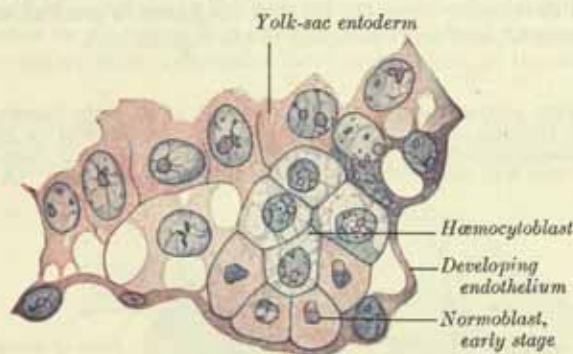
THE DEVELOPMENT OF THE VASCULAR SYSTEM

The blood-corpuscles and the blood-vessels are derived from *angioblastic tissue*, which differentiates from the mesoderm in three regions, viz.: (a) on the surface

* G. L. Streeter, *Contr. Embryol.*, Carneg. Instn., 14, 1922; F. Wood-Jones and Wen I-Chuan, *J. Anat.*, Lond. 69, 1934.

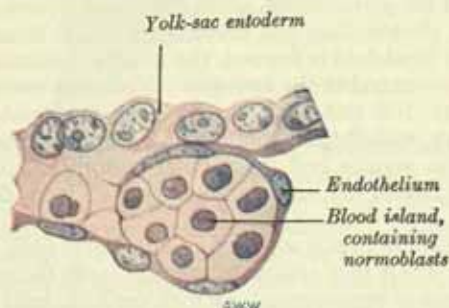
of the yolk-sac, (b) in the body-stalk, and (c) in the chorion.* On the surface of the yolk-sac and in the body-stalk small, more or less spherical, groups of cells are found early in the third week. They are termed *blood-islands* (figs. 165 and 166). The stages of the transformation of blood-islands into blood-containing vessels have not

FIG. 165.—A part of a section through the wall of the yolk-sac of an early human embryo to show an early stage in the differentiation of angioblastic tissue. (Hamilton, Boyd and Mossman's *Human Embryology*, 1945. Reproduced by permission of the authors and publishers.)



yet been demonstrated in detail, but it is generally believed that the peripheral cells of the islands become flattened and form the vascular endothelium, while the central cells become converted into blood-corpuscles (fig. 166). Later these small blood-containing spaces become continuous with one another to form a network of small vessels. In the chorionic end of the body-stalk and in the mesenchyme lining the chorion typical blood-islands are not found, but the cells of the mesenchyme give rise to solid strands of angioblast. Each strand contains two or three rod-shaped

FIG. 166.—A part of a section through the wall of the yolk-sac of an early human embryo, to show a developing blood-vessel including a blood-island. (Hamilton, Boyd and Mossman's *Human Embryology*, 1945. Reproduced by permission of the authors and publishers.)



nuclei arranged in a single row and soon comes to contain a space occupied by one or more nucleated haemoglobin-coloured cells. These spaces run together to form blood-vessels, which are therefore lined by derivatives of the mesenchyme: the precise source of their contained blood-cells is uncertain. The earliest blood-vessels, therefore, are formed at several separate centres; from the walls of these vessels buds grow out, become vascularised and converted into new vessels, and join with those of neighbouring areas to form a close meshwork. The heart and the blood-vessels of the embryo arise from angioblastic tissue differentiated from the intra-embryonic mesoderm. Prior to the establishment of the circulation (p. 156), new

* J. L. Bremer, *Anat. Rec.*, **8**, 1914; Donald McIntyre, *Trans. Roy. Soc. Edin.*, **55**, 1926; A. T. Hertig, *Contr. Embryol.*, *Carneg. Instn.*, **25**, 1935; William Bloom and G. W. Barthelmez, *Am. J. Anat.*, **67**, 1940.

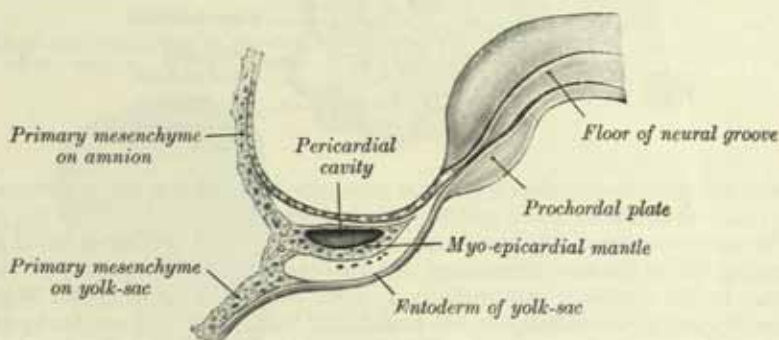
vessels develop *in situ*, but thereafter they all take origin as outgrowths from pre-existing vessels.

The development of the blood corpuscles has already been described (pp. 51, 52).

THE DEVELOPMENT OF THE HEART *

The human heart, like the hearts of all vertebrates, is formed by the fusion of two symmetrically developing tubes (p. 86), but the fusion is gradual, commencing at the bulbar, or arterial, end and extending to the venous end.

FIG. 167.—Median section through the cephalic end of an early human embryo to show the position of the pericardium before the formation of the head-fold. A few scattered angioblasts are seen between the cardiogenic plate and the yolk-sac; they will ultimately form the endothelial heart tubes. (After Carl L. Davis.)



The pericardial cavity can be identified before the head-fold is formed or while it is in process of formation, at a stage when the embryo possesses only two somites. The heart is then represented only by groups of angioblasts which lie between the pericardium and the endoderm of the yolk-sac (fig. 167). At this stage the ventral (or yolk-sac) wall of the pericardium, which is destined to form both the *epicardium* and the *myocardium*, is thicker than the dorsal wall and is termed the *myo-epicardial mantle*. When the head-fold is formed, the mantle becomes the dorsal wall of the pericardium and lies ventral to the fore-gut. While this reversal of the pericardium is taking place (figs. 168 and 169), the cardiogenic angioblastic tissue gives rise to two paramedian endothelial tubes which rapidly fuse to form a tubular heart. Except at its venous end the tubular endothelial heart is separated from the *myo-epicardial mantle* by an interval occupied by a formless jelly-like substance (fig. 170).

The dorsal aortæ arise *in situ* as paired endothelial vessels. They extend caudally into the body-stalk, where they establish continuity with the umbilical arteries, which precede them in time of appearance. At their cephalic ends the dorsal aortæ curve ventrally round the sides of the fore-gut to reach the pericardium to become continuous with the cephalic end of the endothelial heart tube, thus forming the first pair of aortic arches † (fig. 171).

A transverse groove appears on the surface of the heart tube about its middle and indicates the junction of the *bulbus cordis* with the *ventricle*. The *bulbus* is situated cranial to the groove and is continuous with the first pair of aortic arches. The *ventricle* shows a second groove at its caudal end where it opens into a *common atrium*, which lies at first in the floor of the pericardium (septum transversum) and

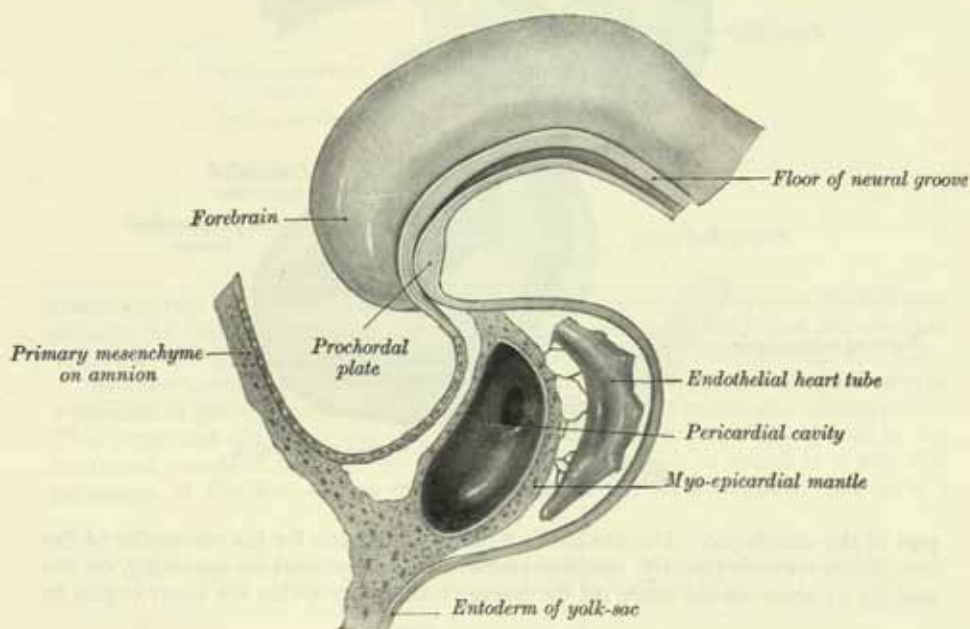
* See A. Girgis, *Proc. Zool. Soc. London*, 1930 and 1933; Carl L. Davis, *Contr. Embryol., Carnegie Instn.*, 19, 1927; D. Waterston, *Trans. Roy. Soc. Edinburgh*, 52, 1918; and J. Tandler, *Keibel and Mall's Manual of Embryology*, 1912.

† In lower vertebrates the heart and aortæ are laid down before the formation of the head-fold and the arteries communicate with the caudal end of the heart. When the head-fold forms, the ends of the heart are reversed and the cephalic ends of the dorsal aortæ are curved forwards round the sides of the fore-gut to form the first aortic arches.

is disposed transversely (fig. 174, *A*). On each side the common atrium is joined caudally by a short venous trunk, formed by the union of the corresponding umbilical vein with veins issuing from the vitelline (yolk-sac) plexus. These trunks represent the right and left *horns* of the *sinus venosus* so that the common atrium may justifiably be termed a common sinu-atrial chamber.

Early in the fourth week the heart tube undergoes a striking change. Hitherto the pericardium has been increasing in length proportionately with the heart, but now the heart tube begins to grow more rapidly than the pericardium and, as a result, the bulbo-ventricular tube bulges ventrally and caudally, forming a U-shaped loop of which the bulb forms the right limb and the ventricle the left. On account of this loop—which is a conspicuous feature throughout the fourth and fifth weeks—a deep *bulbo-ventricular notch* is apparent on the outside of the heart

FIG. 168.—Median section through the cephalic end of a young human embryo, showing the head-fold in process of formation and its effect on the position of the pericardium. Compare with figs. 167 and 169. (After Carl L. Davis.)

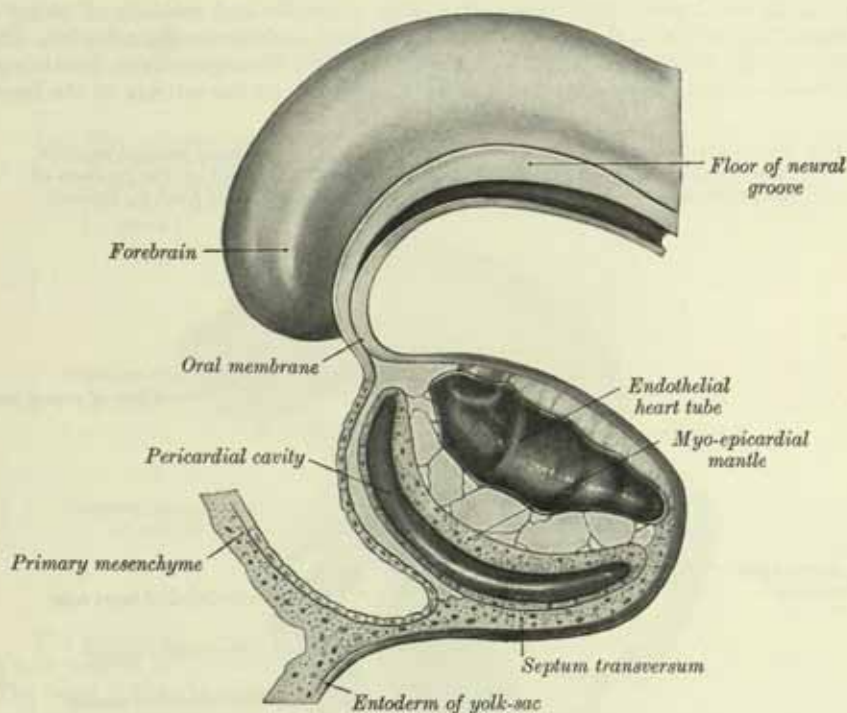


(fig. 171) and a corresponding *bulbo-ventricular ridge* projects into the interior. The dorsolateral recesses of the pericardium deepen and approach one another (fig. 170) and fuse, completing the myo-epicardial covering of the heart and converting its hitherto broad dorsal attachment into a dorsal mesentery. This dorsal mesocardium is very transient and when it breaks down early in the fourth week a passage is established across the pericardial cavity from side to side dorsal to the heart. This passage persists as the *transverse sinus of the pericardium*. While these changes are occurring in the bulbo-ventricular part of the heart, the atrial part is not unaffected, for the atrio-ventricular opening moves headwards and to the left and both parts of the common atrial or sinu-atrial chamber grow headwards into the pericardial cavity and occupy its dorsal portion. Owing to these changes (fig. 174, *B*) the atrio-ventricular canal for a time connects the left atrium to the ventricle and venous blood from the right side has to pass through both atria.

At this stage (fig. 181), which is reached about the middle of the fourth week of development, the bulbus cordis communicates with the dorsal aortae through the first pair of aortic arches and these, in turn, are connected with the capillary plexus associated with the developing cerebral vesicles. From this plexus the primitive head vein passes caudally but it ends blindly before it reaches the heart. The inter-segmental arteries are beginning to grow out from the dorsal aorta on each side but they have not yet established connexions with the corresponding veins, and the posterior cardinal veins, which later drain the body-wall caudal to the heart, are

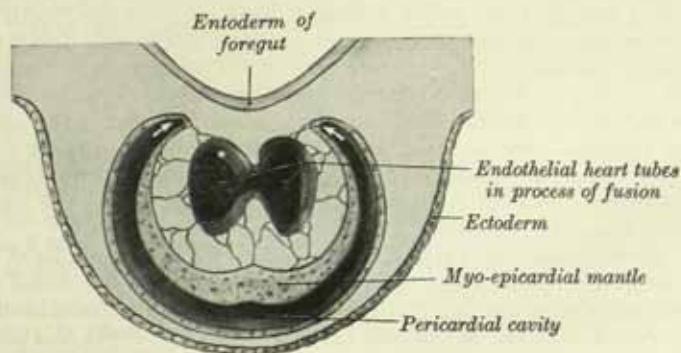
only in process of development. The umbilical arteries and veins are present and, early in the fourth week, their terminals and radicles, respectively, link up with the capillaries which have developed in the chorionic villi, establishing the chorionic

FIG. 169.—Median section through the cephalic end of a young human embryo, after completion of the head-fold and reversal of the pericardium. Compare with figs. 167 and 168. (After Carl L. Davis.)



part of the circulation. Despite the fact that the channels for the remainder of the circulation are only partially established there is good ground for assuming, on the analogy of observations made on the living chick embryo, that the heart begins to

FIG. 170.—A horizontal section through the pericardium and developing heart of the embryo shown in fig. 169. (After Carl L. Davis.) The arrows indicate the directions in which the dorsolateral recesses of the pericardium deepen so as to define the transient dorsal mesocardium.

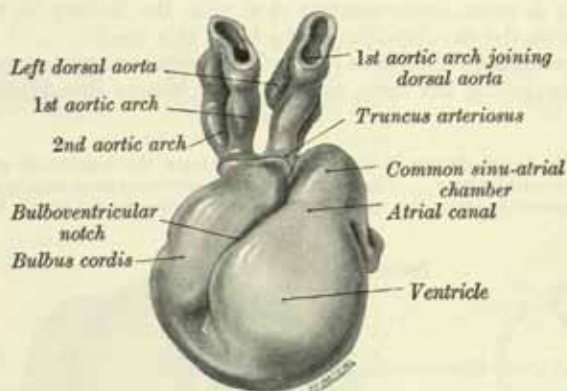


beat about this time. Under the conditions which exist the result can only be of an 'ebb and flow' nature, but this serves to effect some movement in the fluid which

fills the pericardial cavity, the coelomic ducts and the exocoelom (p. 81) and on which the embryo still depends for a considerable part of its nourishment.

Towards the end of the fourth week the connexion between the bulbus cordis and the first pair of aortic arches lengthens to form the *truncus arteriosus*, and the cranial end of this vessel becomes connected to the dorsal aortae by the remaining (five) pairs of aortic arches. By this time the venous drainage of the body-wall and neural tube has been established. On each side an *anterior cardinal vein*, from the

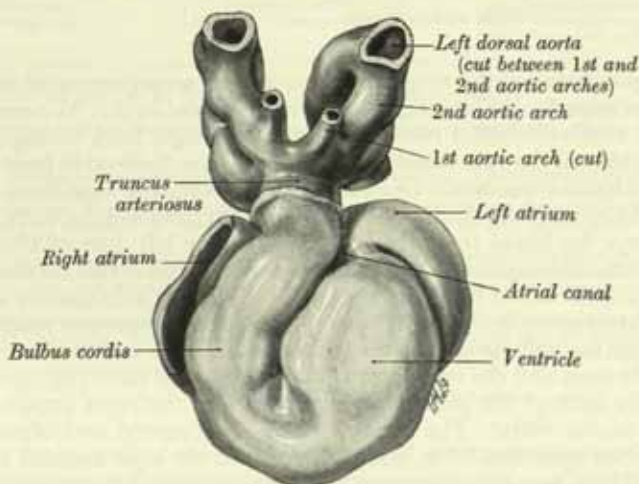
FIG. 171.—The heart of a 0.95 mm. rabbit embryo. Viewed from the ventral side. (Drawn from a model by G. Born.)



headward end of the embryo, unites with a *posterior cardinal vein* from the tail end, to form the *duct of Cuvier*, and this vessel opens close to the umbilical and vitelline veins into the dorso-caudal part of the common sinu-atrial chamber (fig. 174, C).

As the chorionic circulation has already been established, the embryo is now in a position to derive nourishment from the maternal blood in the intervillous space. This important change is not effected suddenly, for at first the blood-cells in the heart and vessels of the embryo are not numerous enough to enable it to take full advantage of this new source of nourishment and it would appear that, until a

FIG. 172.—The heart of a 1.7 mm. rabbit embryo. Viewed from the ventral side. (Drawn from a model by G. Born.)



sufficient number of blood-cells is available, the embryo continues to draw upon the coelomic fluid.

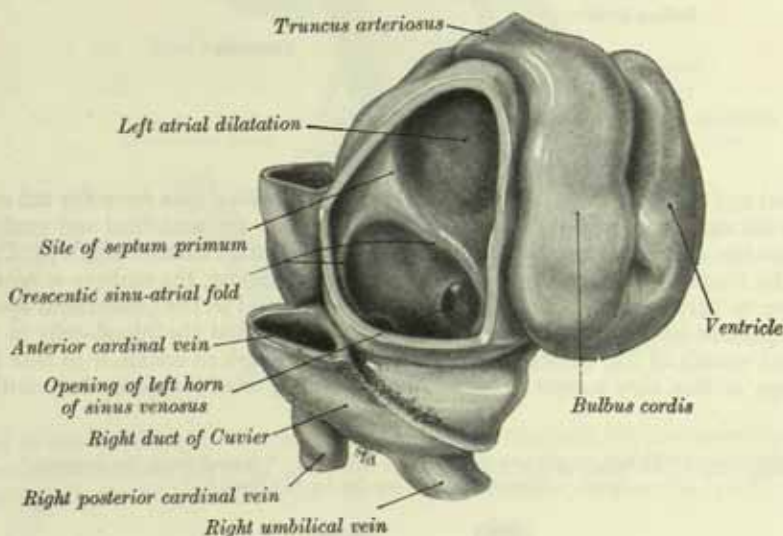
The separation of the *sinus venosus* from the *atrium* completes the definition of

the primitive chambers of the heart. A crescentic groove appears on the left wall of the sinu-atrial chamber and rapidly deepens towards the right so that the left horn of the sinus venosus loses its connexion with the left atrium and becomes linked to the right horn by a part separated off from the caudal aspect of the sinu-atrial chamber which can be regarded as the *body* of the sinus venosus. At the same time the right horn becomes more clearly demarcated from the right atrium and its connexion with the atrium—which is widely open in fig. 173—becomes relatively smaller. The right and left parts of the atrium grow headwards so as to occupy the dorsal part of the pericardial cavity and later they bulge forwards at the sides of the bulb (fig. 175).

The embryo has now attained a length of nearly 4 mm. (fig. 182). It possesses 28 somites and has almost completed the fourth week of development. From this stage onwards it is more convenient to deal with the history of the individual chambers than with the development of the heart as a whole.

The sinus venosus.—The right horn of the sinus venosus increases rapidly in size at the expense of the left horn, owing to the changes already outlined and to

FIG. 173.—The heart shown in fig. 172, viewed from the right side and slightly from the ventral aspect. The right wall of the common sinu-atrial chamber has been removed to show the interior. (Drawn from a model by G. Born.)

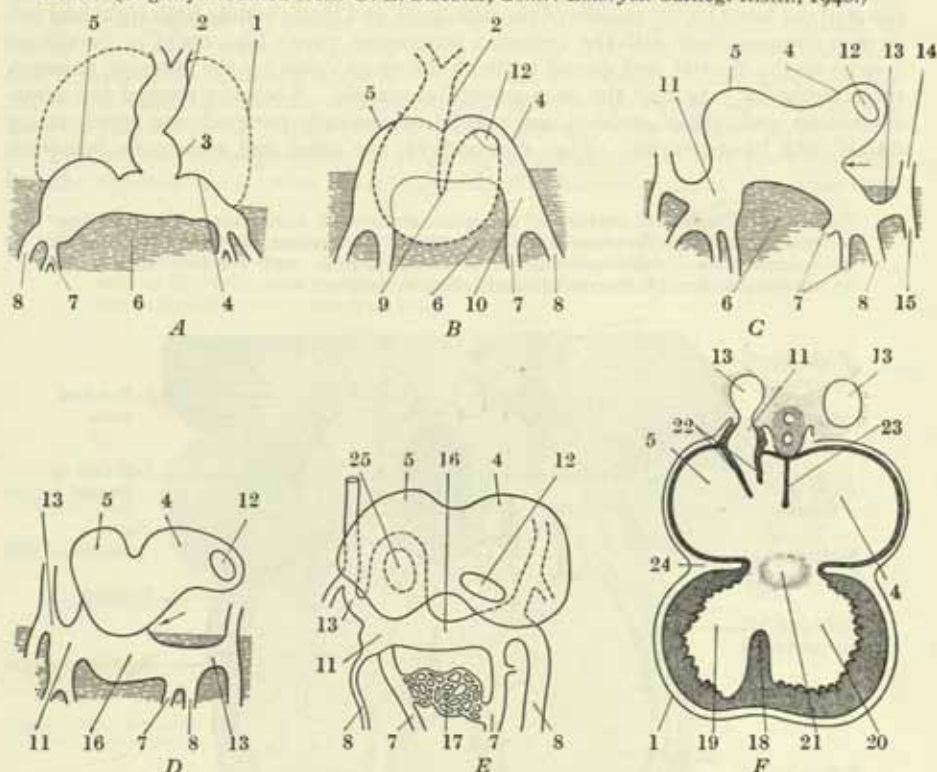


those brought about in the originally symmetrical arrangement of the umbilical and vitelline veins by the development of the liver (p. 175). As a result of these changes the vitello-umbilical blood-flow enters the right horn through a wide but short vessel, termed the *vena hepatis communis*, which is destined to form the cephalic end of the inferior vena cava. In addition to this vein the right horn receives the right duct of Cuvier (from the body-wall of the right side) and the body of the sinus, which conveys the blood from the left horn and the left duct of Cuvier. Later, when transverse connexions are established between the cardinal veins of the two sides (fig. 192), the blood from the body-wall of the left side reaches the heart *via* the veins of the right side. The left duct of Cuvier then becomes much reduced in size and forms the oblique vein of the left atrium and the fold of the left caval vein while the left horn and the body persist as the coronary sinus (fig. 190).

The right horn of the sinus venosus opens into the right atrium through its dorsal and caudal walls. The orifice, which is elongated and often slit-like, is guarded by two muscular folds, which are termed the *right* and *left venous valves* (fig. 175). These two valves meet at the cephalic end of the orifice and become continuous with a fold which projects into the atrium from its roof and is termed the *septum spurium*. At the caudal end of the orifice the two valves meet and fuse with the dorsal endocardial cushion of the atrial canal. The cephalic part of the right venous valve disappears, but its position is indicated in the adult

heart by the crista terminalis of the right atrium; its caudal part forms the valve of the coronary sinus and most of the valve of the inferior vena cava. The medial (or left) end of the valve of the inferior vena cava is formed by a small fold which pro-

FIG. 174.—A series of diagrams to illustrate early stages in the development of the heart. (Slightly modified from G. L. Streeter, *Contr. Embryol. Carneg. Instn.*, 1948.)



1. Outline of pericardium.
2. Bulbus cordis.
3. Common ventricle.
4. Left atrium.
5. Right atrium.
6. Septum transversum.
7. Vitelline vein.
8. Umbilical vein.

9. Bulbo-ventricular notch.
10. Left horn of sinus venosus.
11. Right horn of sinus venosus.
12. Atrio-ventricular canal.
13. Duct of Cuvier.
14. Anterior cardinal vein.
15. Posterior cardinal vein.
16. Body of sinus venosus.

17. Hepatic sinusoids.
18. Ventricular septum.
19. Right ventricle.
20. Left ventricle.
21. Dorsal a.-v. cushion.
22. Venous valves.
23. Septum primum.
24. Pericardial cavity.
25. Sinu-atrial orifice.

A. (Early 4th week. 10 somites.) Bulbar and ventricular parts of heart tubes have fused, but the two atria, which are beginning to rise up into the pericardial cavity and communicate freely with each other and with the ventricle are still easy to identify as separate entities.

B. (13 somites.) Bulbo-ventricular loop, shown as dotted outline, has formed, the atria have risen up further into the pericardial cavity, and the a.-v. canal communicates directly with the left atrium only.

C. (Middle of 4th week. 20 somites.) Bulbo-ventricular loop not shown. Veins of body-wall drain into common vitello-umbilical trunk through duct of Cuvier. A sulcus (shown by the small arrow) is beginning to cut off the caudal part of the common atrial cavity to form the sinus venosus.

D. (24 somites.) The sulcus (shown by the small arrow) has deepened and the left half of the sinus venosus has been separated off from the left atrium. The a.-v. canal still communicates directly with the left atrium only.

E. (Early 5th week. 30 somites.) Separation of sinus venosus has proceeded further and its right and left horns and body can now be identified. They are rising up into the pericardial cavity dorsal to the atria, and the right horn opens into the right atrium through the dorsal wall of the latter. The a.-v. canal is beginning to move towards the right.

F. (Early 6th week. 7.5 mm. C.R. length.) This is an oblique section passing through all the chambers of the heart. The septum primum and the ventricular septum are forming, and the dorsal atrio-ventricular cushion can be seen on the dorsal wall of the widely open a.-v. canal, which is now approximately median in position.

Note.—A, B, C, D, and E are outlines drawn from the ventral aspect.

jects from the dorsal wall of the sinus venosus and is termed the *sinus septum*. In the embryo the sinus septum intervenes between the orifice of the vena hepatis communis and the opening of the body of the sinus.

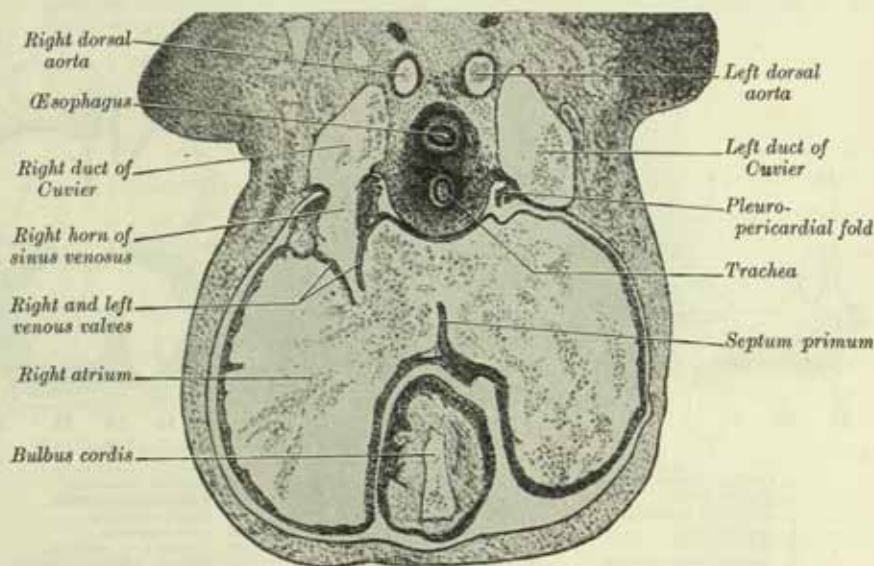
The left venous valve blends with the right side of the atrial septum and usually no trace of it can be seen in the adult heart.

As the venous valves undergo these changes the right horn of the sinus venosus

becomes incorporated in the right atrium and forms its dorsal wall, medial to the crista terminalis. This part of the adult atrium is often termed the *sinus venarum*.

The atria.—As already stated, the common atrium is derived from the cranial part of the sinu-atrial chamber. It receives the opening of the sinus venosus in its dorsicaudal part to the right of the median plane, while its ventral part communicates with the ventricle through the atrial canal, which resumes its position in the median plane of the heart by the middle of the fifth week and then permits both right and left atria to communicate with the common ventricular cavity (fig. 174, *F*). Swellings appear in the ventral and dorsal walls of the atrial canal in the interval between the endothelial tube and the myo-epicardial mantle. They are termed the *atrio-ventricular endocardial cushions* and consist of a simple mesenchyme which stains darkly with hæmatoxylin. They encroach on the canal and eventually fuse with

FIG. 175.—Transverse section of a human embryo, 8 mm. long. Observe how the atria bulge forwards on either side of the bulbus cordis. The septum primum has broken down in its dorsal portion and the two atria communicate through the ostium secundum or foramen ovale.



each other, leaving a relatively small orifice on each side. The fused cushions constitute the *septum intermedium* (of His), and the two small orifices become the right and left atrioventricular openings.

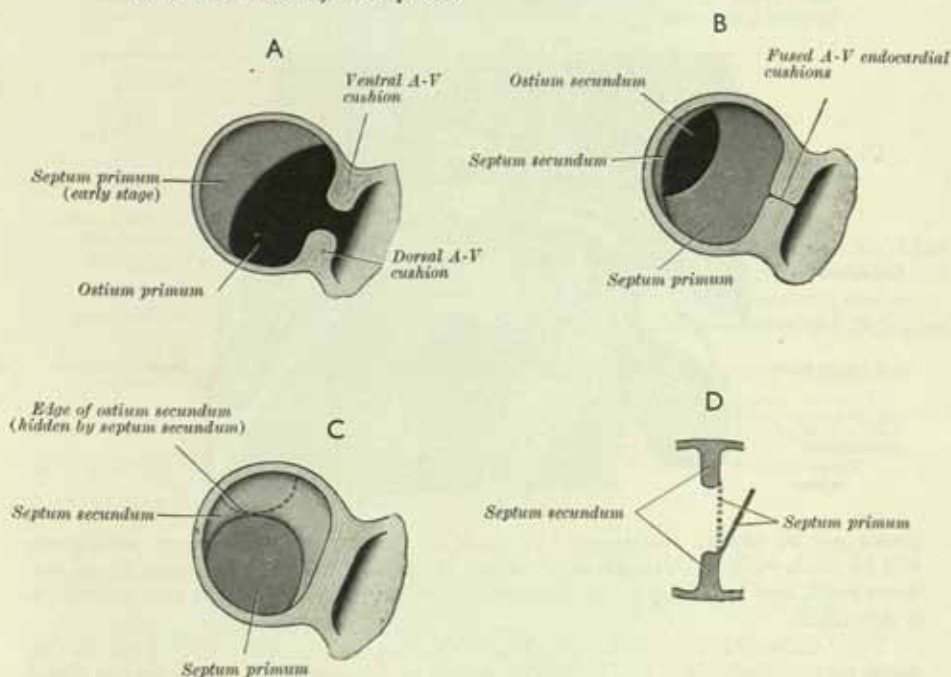
The internal separation of the two atria is effected by the growth of two septa. The first to appear is termed the *septum primum*, and it grows from the dorsal and cephalic wall as a sickle-shaped fold (fig. 176, *A*), which is separated from the left venous valve by an interval named the *intersepto-valvular space*. The ventral horn of the sickle reaches the ventral atrio-ventricular cushion, and the dorsal horn reaches the dorsal cushion.* Ventral and caudal to the advancing edge of the septum the two atria communicate through the *ostium primum* (fig. 176, *A*). Free passage of blood from the right atrium to the left is essential throughout fetal life, as the oxygenated blood from the placenta reaches the heart by the inferior vena cava (p. 723), and, therefore, as the ostium primum becomes reduced in size, the dorsal part of the septum primum breaks down and a new communication, termed the *ostium secundum*, is formed between the two atria before the end of the fifth week. The ostium primum becomes occluded completely by the fusion of the edge of the septum primum with the fused atrio-ventricular cushions, and

* The terms ventral and dorsal refer to the positions of the cushions after the atrium has come to lie dorsal to the bulbus cordis. Actually the ventral cushion is ventri-cephalic and the dorsal cushion dorsi-caudal in position, but the terms ventral and dorsal are in general use and will be retained in the subsequent description.

it should be noted that this fusion occurs in the median plane. The ostium secundum enlarges sufficiently to ensure the free passage of blood from the right atrium to the left (fig. 176, *B*), and it persists throughout intra-uterine life as the *foramen ovale*. At first this opening is situated in the cephalic and dorsal portion of the septum primum but its position becomes modified until it lies in its cephalic and ventral part (fig. 176, *C*). Towards the end of the second month the muscular wall of the atrium becomes inflected to form a crescentic septum on the right side of the septum primum. This inflection is termed the *septum secundum*, and it involves more than the whole width of the intersepto-valvular space, so that the dorsal attachments of the septum primum and the left venous valve are carried into the interior of the atrium (fig. 177) on its left and right surfaces respectively.

The superior and inferior horns of the septum secundum at first grow ventrally but the superior horn grows much more rapidly than the inferior and fuses first

FIG. 176.—Diagrams representing three stages in the development of the atrial septum, viewed from the right side. The heart has been divided in its long axis to the right of its median plane and only the atria and the adjoining part of the ventricular cavity are depicted.



A. The septum primum has not yet obliterated the original communication between the two atria and the atrioventricular endocardial cushions have not yet fused. *B.* The atrioventricular endocardial cushions have fused with each other and with the septum primum, which has broken down in its dorsal part. The ostium secundum, thus formed, subsequently moves to the position shown in *C*. *C.* The septum secundum has formed and hides the ostium secundum, the margins of which are indicated by the curved, dotted line. *D.* A section to show the valve-like character of the ostium secundum. When the pressure in the right atrium exceeds that in the left atrium, blood passes from the right to the left side of the heart, but when the two pressures are equal the septum primum assumes the position indicated by the dotted outline.

with the septum intermedium and is then continued to form the *sinus septum* (p. 159). Thus the free edge of the septum secundum is at first directed ventrally and caudally and later caudally; it overlaps the foramen ovale (fig. 176, *D*) so that the septum primum can act as a flap-like valve. As the blood-pressure is greater in the right atrium than it is in the left, the blood flows from right to left, but not in an opposite direction. After birth the intra-atrial pressures are equalised, and the free edge of the septum primum is therefore kept in contact with the left side of the septum secundum and fusion occurs. Not infrequently the fusion is incomplete, but the opening left is usually small and valvular and has no functional significance.

At an early stage in the development of the septum primum a single, common pulmonary vein, the origin of which is still in doubt, can be identified opening into

the caudal part of the dorsal wall of the left atrium close to the septum. This trunk is formed by the union of a right and a left pulmonary vein, and each of these is formed in turn by two small veins issuing from the developing lung-bud. Subsequently the common trunk and the two veins forming it expand and are incorporated in the left atrium to form the greater part of its cavity. This expansion reaches as far as the orifices of the four veins, which thus open separately into the left atrium. During the second month the two atria bulge ventrally one on each side of the bulbus cordis, which lies in a groove on their ventral surface (fig. 175). These projecting parts of the atria form the auricles of the adult heart, while their dorsal parts expand to form the atria proper.

The ventricles, bulbus cordis and the truncus arteriosus.—The process of separation of the two ventricles is intimately related to the separation of the aortic and pulmonary orifices at the distal end of the bulbus and to the subdivision of the truncus arteriosus (p. 157) into pulmonary and aortic channels. These two pro-

FIG. 177.—Transverse section through the thorax of a human embryo, 21 mm. long, showing the inflexion of the muscular atrial wall to form the septum secundum. Note the vacuolated condition of the esophagus which is characteristic at this stage.



cesses are so closely interdependent that the history of the truncus arteriosus will be dealt with in this section, although it takes no part in the formation of the heart itself, and both will be considered before the separation of the two ventricles is described.

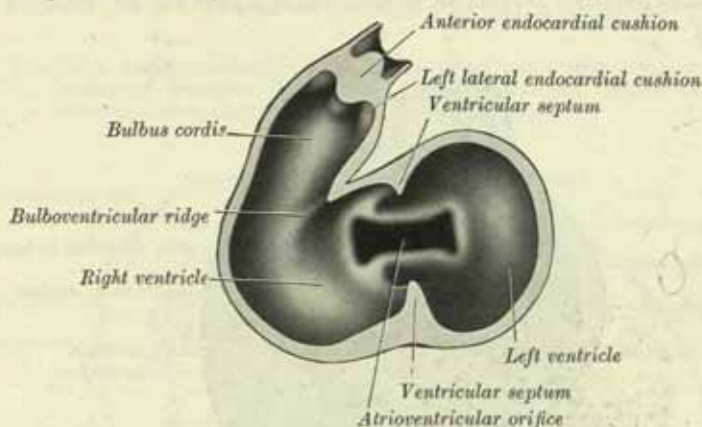
Four endocardial cushions—a ventral, a dorsal, a right and a left—form in the distal part of the bulbus, and the right and left cushions fuse to constitute the *distal bulbar septum*. This septum separates a ventral, or pulmonary, orifice from a dorsal, or aortic, orifice, and later the cushions become modified to form the semilunar valves.

The separation of the pulmonary trunk from the aorta is a more complicated process. Two ridge-like thickenings project into the interior of the truncus arteriosus. Proximally, the ridges are placed on the lateral walls of the vessel, but as they are traced away from the heart, the right ridge passes obliquely on to the ventral wall and then on to the left wall, while the left ridge extends on to the dorsal wall and then on to the right wall (fig. 179). The ridges are therefore spiral and their fusion forms the *spiral aortopulmonary septum*. At its proximal end this septum meets and fuses with the distal bulbar septum, and on account of its spiral character the pulmonary trunk, which lies ventral to the aorta at its orifice, curves round to its left side as it ascends, and finally lies dorsal to it (fig. 179). At its distal end the aortopulmonary septum meets the dorsal wall of the aortic sac (see p. 168) headwards of the point where it is joined by the sixth pair of aortic arches, and as a result these arches become branches of the pulmonary trunk, while the other aortic arches are left in communication with the aorta (fig. 179).

The separation of the two ventricles from each other has to be effected in such a way as to leave the right ventricle in communication both with the right atrium and with the pulmonary artery, and the left ventricle in communication both with the

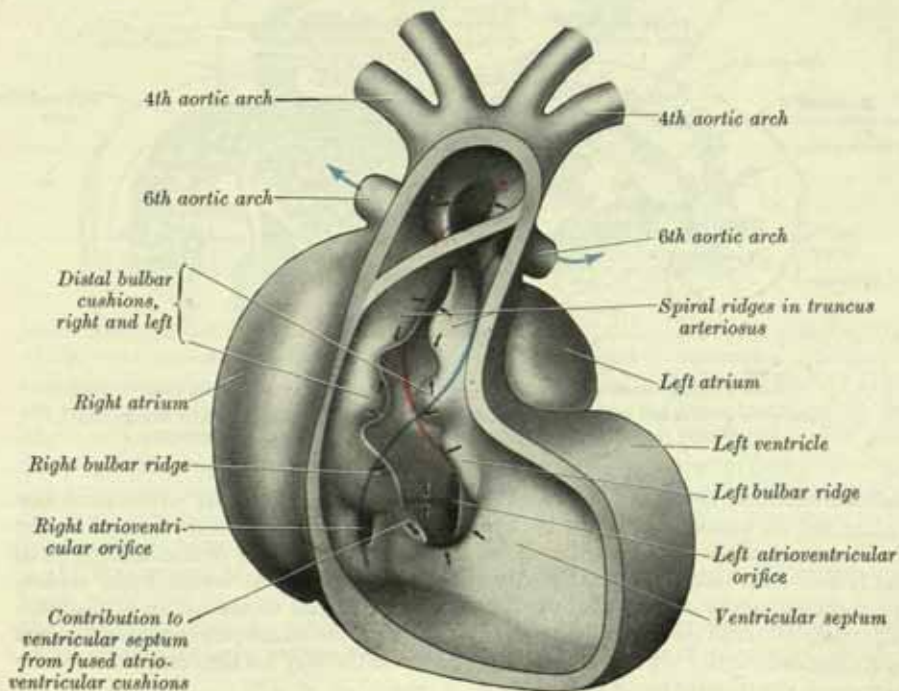
left atrium and the aorta. On account of the complicated character of the changes which are necessary three distinct factors contribute to the formation of the adult ventricular septum, viz.:—(a) the *ventricular septum*, (b) the *proximal bulbar septum*, and (c) the *atrioventricular endocardial cushions*.

FIG. 178.—A diagram showing the relations at an early stage between the atrio-ventricular opening and ventricles, the cavity of the bulbus cordis, and the bulboventricular ridge. The endocardial cushions at the distal end of the bulb are shown in a more differentiated state than they really exhibit at this stage. (J. Ernest Frazer.)



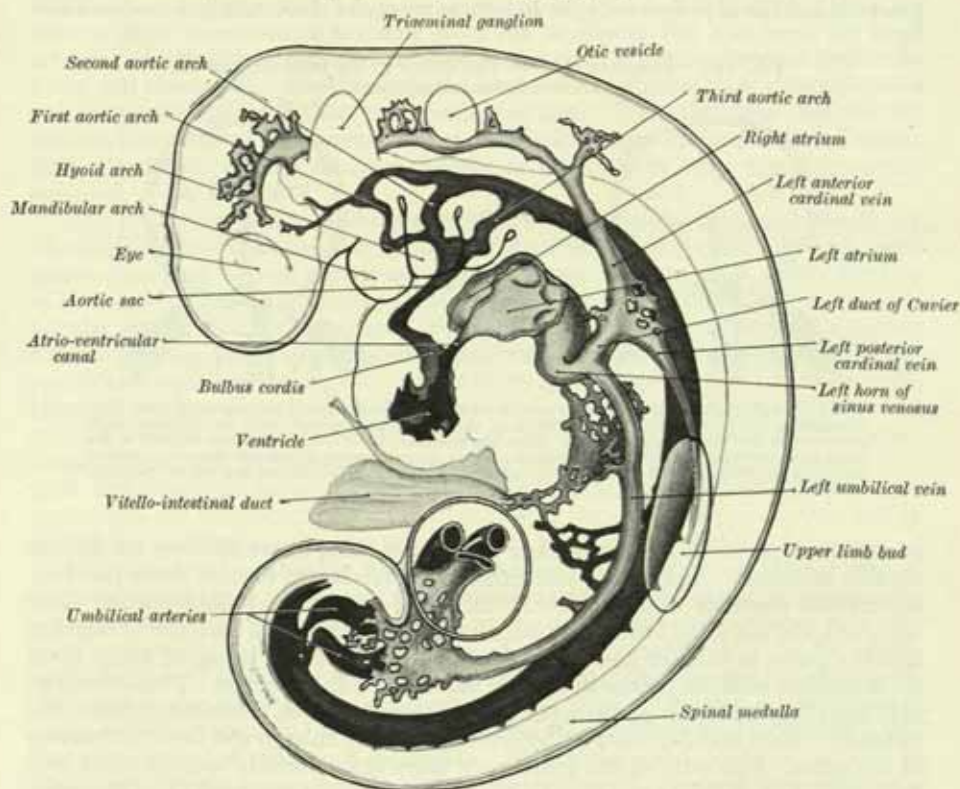
(a) During the fifth week the right and left ventricles are indicated as slight projections on the surface of the common ventricle. It is uncertain whether the right ventricle is to be regarded as a derivative of the primitive ventricle (Frazer) or of the caudal end of the primitive bulbus (Streeter). In either event the appearance

FIG. 179.—A diagram to show the mode of formation of the septa which separate the aortic and pulmonary channels in the embryonic heart. The *red* arrow indicates the aortic channel and the *blue* arrow the pulmonary. The small *black* arrows indicate the directions of growth. (Drawn from a plasticine model made by the late Professor James Whillis.)



(b) The *proximal bulbar septum* separates the bulbus cordis into pulmonary and aortic channels, and is formed by the *right and left bulbar ridges*, which are in continuity with the corresponding bulbar endocardial cushions. The right bulbar ridge grows across on to the dorsal wall of the bulb and the right extremity of the fused atrioventricular endocardial cushions to reach the dorsal end of the free, sickle-shaped edge of the ventricular septum, and in doing so obliterates the ventral or cephalic part of the right atrioventricular orifice (fig. 179). The left bulbar ridge grows across on to the ventral wall of the bulb to reach the ventral or cephalic end of the ventricular septum. Although the two bulbar ridges fuse with each other and so separate the conus arteriosus of the right ventricle from the aortic vestibule, the

FIG. 182.—Profile reconstruction of the blood-vascular system of a human embryo, having 28 somites. C.R. length, 4 mm. Estimated age, 26 days. (G. L. Streeter, *Contr. Embryol.*, Carneg. Instn., 30, 1942.)



Note.—Only the endothelial lining of the heart chambers is shown and, as the muscular wall has been omitted, the pericardial cavity appears to be too big for the contained heart. Observe that the atrioventricular canal still connects the left atrium with the single ventricle.

caudal edge of the septum so formed is separated from the free sickle-shaped edge of the ventricular septum by a gap through which the two ventricles continue to communicate (fig. 180). This gap is closed by the growth of cushion tissue * from the right extremity of the fused atrio-ventricular cushions, and this fuses, on the one hand, with the caudal border of the proximal bulbar septum and on the other with the free sickle-shaped margin of the ventricular septum. The dorsal part of the bulb becomes absorbed almost entirely, but its position is indicated by the dorsal wall of the aortic vestibule, which, however, is formed to a large extent by the fused atrio-ventricular endocardial cushions.

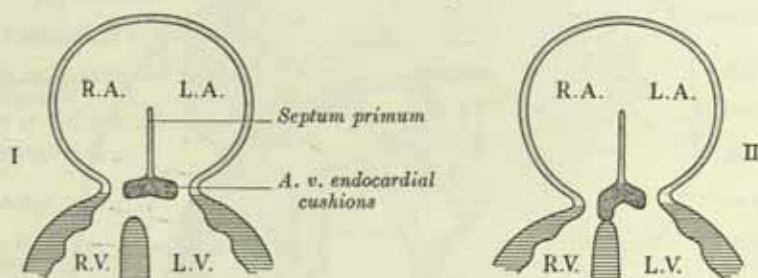
(c) At the time of their fusion the atrioventricular endocardial cushions are very large relative to the size of the atrioventricular orifices. The atrial septum meets the atrial surface of the cushions at their centre, but the ventricular septum meets them near their right extremity. It follows that a portion of the fused cushions

intervenes between the right atrium and the left ventricle, and it is this portion which forms the right wall of the aortic vestibule (*atrioventricular septum*, p. 715). The membranous part of the ventricular septum, which is continuous dorsally with the membranous atrioventricular septum in the adult heart (fig. 673), is formed by the proliferation of cushion tissue from the right extremity of the fused atrioventricular cushions, described above. The persistence of a communication between the two ventricles is due to arrest of development in this region.

It should be observed that the upper and dorsal part of the orifice which lies above the ventricular septum (fig. 179) becomes incorporated in the aortic vestibule and thereafter serves to connect the left ventricle with the aortic channel.

The valves of the heart.—The atrioventricular valves develop as endothelial projections directed towards the ventricles at the atrioventricular orifices. From the first they are connected with the ventricular musculature at their bases and, as growth proceeds and the flaps become enlarged, these muscular trabeculae become freed and

FIG. 183.—Diagram to show two stages in the formation of the adult ventricular septum.



In I, the right and left ventricles communicate with each other, but in II the interventricular communication has been closed by the fusion of the ventricular septum with the enlarged right extremity of the fused a. v. cushions. Note the position of the septum primum relative to the fused a. v. cushions, and observe that in II cushion tissue intervenes between the two ventricles (membranous part of ventricular septum), and also between the right atrium and the left ventricle (atrioventricular septum).

constitute the muscoli papillares, their extremities being converted into the fibrous chordae tendineae. The aortic and pulmonary valves are formed from the four endocardial cushions which appear at the distal end of the bulbus cordis. The completion of the distal bulbar septum results in the division of each lateral cushion into two parts, so that the number of thickenings is increased to six, of which three are associated with the pulmonary orifice and three with the aortic. These thickenings form the rudiments of the aortic and pulmonary valves, while the pouches between the valves and the walls of the vessels gradually enlarge and form the sinuses of the aorta. One cusp of the pulmonary valve lies anteriorly and the other two posterolaterally, whereas one cusp of the aortic valve lies posteriorly and the other two anterolaterally. A rotation of the heart to the left before birth affects the orientation of the cusps of the pulmonary and aortic valves which is reflected in the various schemes for the designation of these cusps. The nomenclature employed above is retained in the description of the adult vessels (pp. 711-717).

The development of the chambers of the heart has now been traced to a stage at which the main features of the adult heart can easily be recognised. It is to be noted that the plan has developed in such a way as to provide for the sudden establishment of the pulmonary circulation at birth, although it is adapted to the persistence of the placental circulation for the remainder of fetal life. The presence of the ductus venosus ensures that the oxygenated blood gains the right atrium with the minimum loss of oxygen to the liver. Relatively little admixture of oxygenated and deoxygenated blood occurs in the right atrium* and nearly all of the oxygenated blood passes through the foramen ovale into the left atrium, so gaining the left ventricle and the aorta. Owing to the fact that the transition from the placental to the pulmonary circulation occurs suddenly at birth, the right ventricle and the pulmonary trunk of the fetus are relatively large although only a small amount of

* A. E. Barclay, J. Barcroft, K. J. Franklin and D. H. Barron, *Brit. J. of Radiology*, 12, 1939.

blood is able to pass through the lungs. In actual fact most of the blood expelled by the right ventricle into the pulmonary trunk passes through the ductus arteriosus into the descending aorta and in order that it may be able to do so it must be under higher pressure than the blood in the aorta. On this account the muscular wall of the right ventricle is thicker than the wall of the left ventricle, a condition which persists throughout fetal life but is rapidly reversed after birth. The origin of the carotid and subclavian arteries from the aorta above the point at which it is joined by the ductus arteriosus may be correlated with the need of the brain for the best available blood-supply and with the size of the upper limbs relative to the lower limbs at birth.

In the early stages of development the arteries of the embryo are disproportionately large (fig. 209) and their walls consist of little more than a single layer of endothelium. At this time the cardiac orifices are relatively large and the force of the cardiac contraction is weak. As a result, despite the rapid rate of the heart, the circulation is sluggish, but this is compensated for by the fact that the tissues are able to draw nourishment not only from the capillaries but also from the large arteries. As the heart muscle strengthens, the cardiac orifices become both relatively and absolutely reduced in size, the large arteries acquire their muscular walls and they too undergo a relative reduction in size. From this time onwards the embryo is dependent for its nourishment on the expanding capillary beds and henceforth the larger arteries function merely as channels to keep them constantly supplied.

The conducting system of the heart.—The atrioventricular node and bundle are identifiable towards the middle of the sixth week of embryonic life. Some investigators claim that the first part to appear is the atrioventricular node which develops as an outgrowth from the dorsal part of the muscular ring surrounding the atrioventricular canal. The atrioventricular bundle is then derived from this by a growth distally passing behind the dorsal endocardial cushion to the free edge of the ventricular septum where it gives rise first to the left and then to the right limbs of the bundle.* Others maintain that the stem of the atrioventricular bundle appears first as a differentiation from the musculature of the dorsal wall of the atrioventricular canal. From this, differentiation spreads proximally to form the atrioventricular node and distally to form the right and left limbs of the bundle.† From its earliest appearance the whole complex is continuous with the muscular tissue of the atrium and of the ventricular wall, and this condition persists to adult life.

The sinu-atrial node is the last part of the conducting system to appear, and its site is indicated by an aggregation of nerve cells and fibres on the wall of the superior vena cava just above its junction with the atrium, before the node itself can be recognised in the latter part of the third month. A narrow band of muscle on the ventrolateral surface of the superior vena cava undergoes peculiar changes which eventually result in the characteristic adult structure (p. 720). Although at first situated on the superior vena cava, in late fetal life it becomes incorporated in the atrial wall at the upper end of the sulcus terminalis. Its cephalic edge, however, remains in continuity with the muscular coat of the vessel, although elsewhere it is continuous with the muscular wall of the atrium. The node does not appear until the right horn of the sinus venosus has been incorporated in the right atrium.

It will be noted that the heart commences to beat (p. 156) prior to the development of the conducting system and that the circulation is established before a competent valvular mechanism has been laid down. Streeter ‡ associates the latter fact with the incompressible but elastic character of the jellylike substance which occupies the myo-endocardial interval (p. 154).

A brief summary of the common congenital abnormalities of the heart will be found on p. 726.

The further development of the arteries.—Apart from the aortae none of the main vessels of the adult arise as single trunks in the embryo. At the site of each vessel a capillary network is laid down, and by the enlargement of definite paths in this network the larger arteries and veins are formed. The branches of the main arteries are not always simple modifications of the vessels of the capillary network, but may arise as new outgrowths from the enlarged stem.

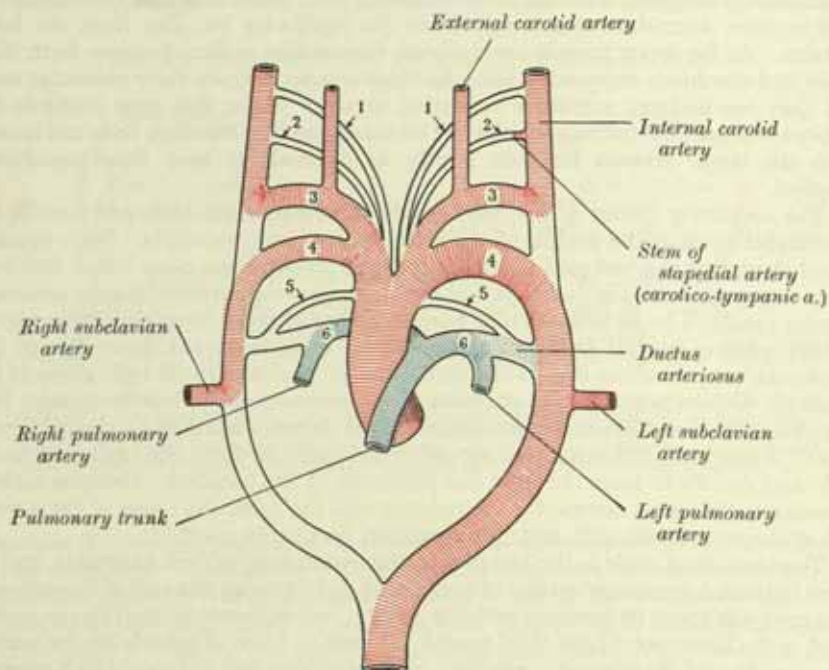
* R. F. Shaner, *Anat. Rec.*, **44**, 1929. E. W. Walls, *J. Anat. Lond.*, **81**, 1947.

† E. J. Field, *Brit. Heart J.*, **13**, 1951. A. R. Muir, *J. Anat. Lond.*, **88**, 1954.

‡ G. L. Streeter, *Contr. Embryol.*, *Carneg. Instn.*, **31**, 1945.

It has been seen (p. 154) that subsequent to the formation of the head-fold each primitive aorta consists of a ventral and a dorsal part which are continuous through the first aortic arch. The dorsal aortæ run caudally, one on each side of the notochord, but in the fourth week they fuse from about the level of the fourth thoracic to that of the fourth lumbar segment to form a single trunk—the descending aorta. Although in many animals paired ventral aortæ arise from the truncus arteriosus and course headwards on the ventral surface of the pharynx, in the human embryo the ventral aortæ are fused and form a dilated vessel, termed the 'aortic sac' (Congdon).* The first aortic arches run through the mandibular arches, and caudal to them five additional pairs are developed within the corresponding visceral arches; so that, in all, six pairs of aortic arches are formed (figs. 184 and 185). The fifth arches are transient vessels which very soon disappear. When present they usually

FIG. 184.—A scheme of the aortic arches and their transformations.
(After Congdon.)



The vessels left uncoloured disappear entirely in the course of normal development and cannot be identified after birth. The origin of the left subclavian artery later migrates proximally on the arch of the aorta.

connect the fourth aortic arch arteries or subjacent aortic sac with the dorsal ends of the sixth arches. The other arches pass between the aortic sac and the dorsal aortæ.

In fishes the aortic arches persist and give off branches to the gills, in which the blood is oxygenated. In mammals some of the arteries remain as permanent structures, while others disappear or are obliterated (fig. 184).

The aortic sac represents fused, paired ventral aortæ. As the embryo grows and the aorto-pulmonary septum is formed, part of the caudal end of the sac is incorporated in the pulmonary trunk. The cephalic end of the sac becomes drawn out into right and left limbs as the neck lengthens. The right limb becomes the brachiocephalic trunk and the left limb forms that part of the arch of the aorta which lies between the origin of the brachiocephalic trunk and the left common carotid artery. The remainder of the sac contributes to the formation of the arch of the aorta.

The aortic arches.—The first and second aortic arches disappear while the third is forming. Close to its point of origin the hyoid artery gives off the stapedial artery (fig. 185).

Near its ventral end the third aortic arch gives origin to a vascular sprout which

* E. D. Congdon, *Contr. Embryol.*, Carneg. Instn., 14, 1922.

passes headwards and forms the external carotid artery. After the appearance of this vessel, the ventral end of the third aortic arch persists as the common carotid and its dorsal end as the proximal end of the internal carotid artery. The fourth aortic arch of the right side forms the proximal part of the right subclavian, while the corresponding vessel of the left side constitutes the arch of the aorta between the origin of the left common carotid artery and the left subclavian artery. The fifth arch disappears on both sides. The ventral part of the sixth aortic arch of the right side persists as the proximal part of the right pulmonary artery but its dorsal part disappears. The ventral part of the sixth aortic arch of the left side is absorbed into the pulmonary trunk, while its dorsal part persists as the ductus arteriosus; this duct remains pervious during intrauterine life, but is obliterated after birth (p. 725) and forms the ligamentum arteriosum of the adult. The developing lung-buds are first supplied by a capillary plexus derived from the aortic sac. Later, this plexus becomes connected to the dorsal aorta, and this vascular connexion between the latter and the aortic sac constitutes the sixth aortic arch. The continuation of the capillary plexus to the lung-bud thereafter becomes transformed into the definitive pulmonary artery.

*The cranial arteries.**—The internal carotid artery is formed from the dorsal portion of the third arch artery, the dorsal aorta cranial to this and a forward continuation which differentiates, at the time of regression of the first and second aortic arches, from the capillary plexus extending to the walls of the fore- and mid-brain. At its anterior extremity this forward continuation from the dorsal aorta divides into cranial and caudal division, the former terminating in the olfactory region of the fore-brain and the latter sweeping dorsally to terminate on the mid-brain. At the same time bilateral longitudinal channels differentiate along the ventral surface of the hind-brain from a plexus which is fed by segmental and transitory pre-segmental branches from the dorsal aorta and its forward continuation. These longitudinal channels later connect, in front, with the caudal divisions of the internal carotid artery which continues to supply the mid-brain and behind with the vertebral arteries through the first cervical segmental arteries. The longitudinal channels fuse along the ventral surface of the metencephalon to form the *basilar artery*, whilst the caudal division of the internal carotid artery becomes the posterior communicating artery and the stem of the *posterior cerebral artery*, the remainder of which is formed from one of the mesencephalic vessels which is annexed by the backwardly expanding cerebral hemisphere. The cranial division of the internal carotid artery gives rise to the *anterior chorioidal*, *middle cerebral* and *anterior cerebral arteries* and its supply to the olfactory region remains as a small branch of the anterior cerebral artery. The *cerebellar arteries*, of which the superior is the first to differentiate, emerge from the capillary plexus on the walls of the rhombencephalon.

The source of the blood supply to the territory of the fifth cranial nerve varies at different stages in development. When the first and second aortic arch arteries begin to regress the blood supply to the corresponding arches is derived from a transient vessel termed the *ventral pharyngeal artery*, which grows into the region from the aortic sac. It terminates by dividing into *mandibular* and *maxillary branches*. Later a vessel, the *stapedial artery* develops from the dorsal stem of the second arch artery, and passes through the ring of the stapes to anastomose with the cranial end of the ventral pharyngeal artery and thereby annex its terminal distribution. The fully developed stapedial artery possesses three branches, the mandibular, maxillary and *supraorbital*, which follow the divisions of the fifth cranial nerve (fig. 185). The mandibular and maxillary branches arise by a common stem. When the external carotid artery emerges from the base of the third arch it incorporates the stem of the ventral pharyngeal artery and its maxillary branch communicates with the common trunk of origin of the maxillary and mandibular branches of the stapedial artery and annexes these vessels. The proximal part of the common trunk forms the stem of the *middle meningeal artery*. More distally the middle meningeal artery is represented by the proximal part of the supraorbital artery. The maxillary artery becomes the infraorbital artery and the mandibular branch forms the inferior alveolar artery.

When the definitive *ophthalmic artery* differentiates as a branch of the terminal part of the internal carotid artery, it communicates with the supraorbital branch of the stapedial artery the distal part of which becomes the *lacrimal artery*. This retains an anastomotic connexion with the middle meningeal artery. The dorsal stem of the original second arch artery remains as a *carotico-tympanic branch* of the internal carotid artery.

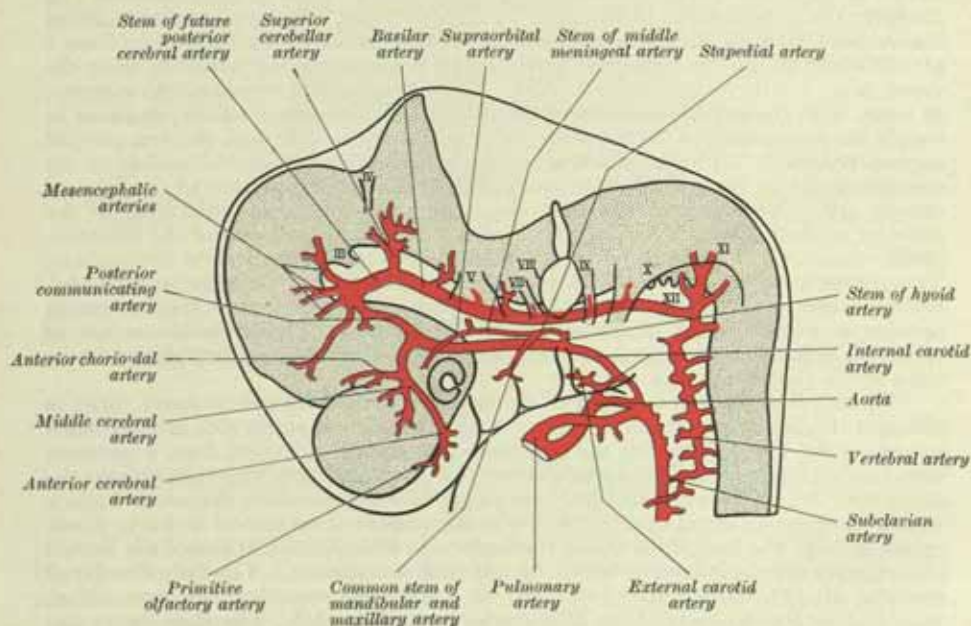
* For details see H. M. Evans in Keibel and Mall's *Human Embryology*, 1912, E. D. Congdon, *Contr. Embryol.*, Carneg. Instn., 14, 1922, and D. H. Padgett, *ibid*, 35, 1948.

The dorsal aortæ (fig. 184).—On the cephalic side of the third aortic arches the dorsal aortæ persist and form the continuations of the internal carotid arteries. Between the third and fourth arches the right dorsal aorta disappears, but from the fourth arch to the point of origin of the seventh intersegmental artery it becomes a portion of the right subclavian artery (fig. 184). Caudal to the seventh intersegmental artery the right dorsal aorta disappears as far as the point where the two dorsal aortæ fuse to form the descending thoracic aorta. The part of the left dorsal aorta between the third and fourth arches disappears, while the remainder persists to form the descending part of the arch of the aorta. A constriction, termed the *aortic isthmus*, is sometimes seen in the aorta between the final site of origin of the left subclavian artery and the attachment of the ductus arteriosus.

In the adult, the right subclavian artery sometimes arises from the arch of the aorta distal to the origin of the left subclavian and then passes upwards and to the right behind the trachea and œsophagus. This condition may be explained by the persistence of the right dorsal aorta and the obliteration of the fourth aortic arch of the right side.

In birds the fourth aortic arch of the right side forms the arch of the aorta; in reptiles the fourth arches of both sides persist and give rise to the double aortic arch of these animals.

FIG. 185.—Diagram to show the origins of the main cranial arteries. (After D. H. Padgett, *Contr. Embryol., Carneg. Instn.*, 32, 1948.)



The heart originally lies on the ventral surface of the pharynx, immediately caudal to the stomodæum (fig. 181); with the elongation of the neck and the development of the lungs it recedes within the thorax, and, as a consequence, the vessels are drawn out and the original position of the fourth and sixth aortic arches is greatly modified. Thus, on the right side the fourth aortic arch recedes to the root of the neck, while on the left side it descends into the thorax. The recurrent laryngeal nerves originally pass to the larynx caudal to the sixth pair of aortic arches, and are therefore affected by the descent of these structures, so that in the adult the left nerve hooks round the ligamentum arteriosum within the thorax; owing to the disappearance of the fifth and the dorsal part of the sixth aortic arch on the right side, the right recurrent laryngeal nerve hooks round the fourth aortic arch, i.e. the commencement of the right subclavian artery.

At first the aortæ are the only longitudinal vessels present, for the branches of the

aortæ all run at right angles to the long axis of the embryo. Later these horizontal arteries become connected in certain situations by longitudinal anastomosing channels, and portions of these longitudinal vessels persist, forming such arteries as the internal thoracic, the inferior epigastric, the gastro-epiploic, etc. Each dorsal aorta gives off segmental branches to the digestive tube (*ventral splanchnic arteries*) and to the Wolffian ridge (*lateral splanchnic arteries*) and *intersegmental* branches to the body-wall (*somatic arteries*).

The *ventral splanchnic arteries* are originally paired vessels which are distributed to the wall of the yolk-sac, but after fusion of the dorsal aortæ they appear as unpaired trunks and are distributed to the primitive digestive tube. Longitudinal anastomosing channels connect these branches along the dorsal and ventral aspects of the tube, forming dorsal and ventral splanchnic anastomoses (fig. 182). The development of these longitudinal vessels obviates the necessity for so many ventral splanchnic arteries, and these are reduced to three—the celiac trunk, superior mesenteric and inferior mesenteric arteries. As the viscera which they supply descend into the abdomen, the origins of these vessels wander in a caudal direction; thus the origin of the celiac artery is transferred from the level of the seventh cervical segment to the level of the twelfth thoracic, the superior mesenteric from the second thoracic to the first lumbar, and the inferior mesenteric from the twelfth thoracic to the third lumbar. The dorsal splanchnic anastomosis persists in the gastro-epiploic, pancreatico-duodenal, and the primary branches of the colic arteries, while the ventral splanchnic anastomosis forms the right and left gastric and the hepatic arteries.

The *lateral splanchnic arteries* supply, on each side, the mesonephros, the testis (or ovary) and the suprarenal gland; all these structures develop, in whole or in part, from the mesoderm of the mesonephric ridge (p. 206). One testicular (or ovarian) artery and three suprarenal arteries persist on each side. The phrenic artery arises as a branch from the first suprarenal artery, and the renal artery as a branch from the third. Additional renal arteries are frequently present and may be looked on as branches of persistent lateral splanchnic arteries.

The *somatic arteries* are intersegmental in position, and they persist, almost unchanged, in the thoracic and lumbar regions, as the posterior intercostal, subcostal and lumbar arteries. Each gives off a dorsal branch which passes backwards in the intersegmental interval and divides into medial and lateral branches to supply the muscles and superficial tissues of the back (fig. 186). In its course this dorsal branch gives off a spinal branch, which enters the vertebral canal and gives off spinal branches to the osteo-ligamentous canal and neural branches to the spinal medulla. Having given off its dorsal branch the intersegmental artery runs ventrally in the body-wall, gives off a lateral branch and terminates by supplying both muscular and cutaneous branches.

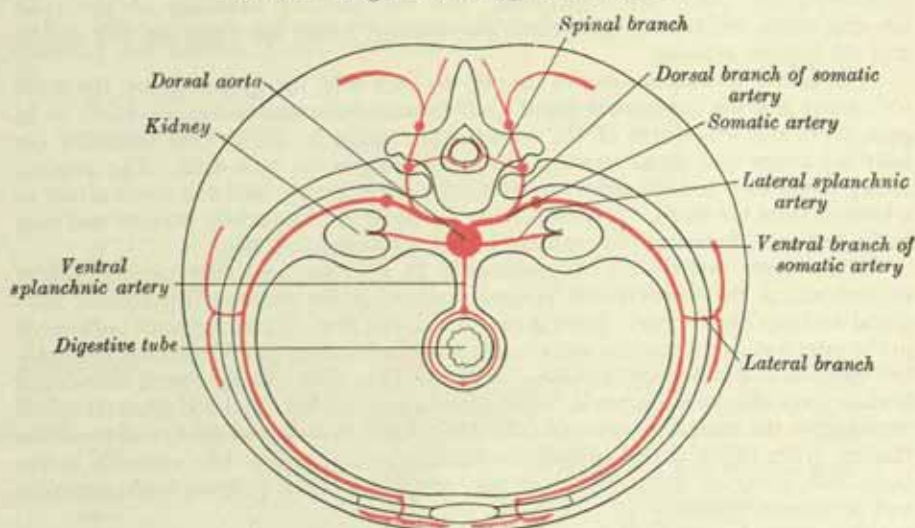
Numerous longitudinal anastomoses link up the intersegmental arteries and their branches with one another (fig. 186). A *post-costal anastomosis* connects the dorsal branches in the interval between the neck of the rib and the vertebral transverse process. This vessel persists in the cervical region where it forms the greater part of the vertebral artery. A *post-transverse anastomosis* also connects the dorsal branches and is responsible for the greater part of the deep cervical artery. A *precostal anastomosis* connects the intersegmental arteries beyond the origins of their dorsal branches. The ascending cervical and the supreme intercostal arteries represent persistent portions of this vessel. Lastly, near the anterior median line the intersegmental arteries become linked up by a *ventral somatic anastomosis*. This vessel persists to a large extent in the adult and is represented by the internal thoracic, the superior epigastric and the inferior epigastric arteries.

The *umbilical arteries* at first appear to be the direct continuation of the primitive dorsal aortæ and they are present in the body-stalk before any vitelline (yolk-sac) or visceral branches can be seen—an indication of the importance of the chorionic as compared with the vitelline circulation in the human embryo. After the fusion of the dorsal aortæ the umbilical arteries arise from its ventrolateral aspect and pass medial to the primary excretory duct (Wolffian duct) on their way to the umbilicus. Later the proximal part of the umbilical artery is joined by a vessel which leaves the aorta at its termination and passes lateral to the primary excretory duct. This new vessel, which possibly may represent the fifth lumbar intersegmental artery, constitutes the dorsal root of the umbilical artery, the original stem being the ventral

root. The dorsal root gives off the axial artery of the lower limb, branches to the pelvic viscera, and, at a more proximal point, the external iliac artery. The ventral root disappears entirely, and the umbilical artery now arises from that part of its dorsal root which lies distal to the external iliac artery, i.e. from the internal iliac artery.

The arteries of the limbs.—Although a number of vessels contribute to the primitive capillary plexus of the upper limb-bud, eventually only one trunk—the subclavian—persists, and it has the position and relations of the *seventh intersegmental artery* and probably represents its lateral branch. The main trunk to the upper limb, which later forms the axillary and brachial arteries, is continued into the forearm deep to the flexor premuscle mass and terminates in a plexiform manner in the developing hand. This vessel ultimately persists as the anterior interosseous artery and the deep palmar arch. A branch from the main trunk passes dorsally between the developing radius and ulna and constitutes the posterior interosseous artery, while a second branch accompanies the median nerve into the hand, where it ends in a superficial capillary plexus. The radial and ulnar arteries are the latest arteries to appear in the forearm; at first the radial artery arises at a higher level than the ulnar and crosses in front of the median nerve, giving branches to the biceps muscle.

FIG. 186.—Diagram of the segmental arteries.

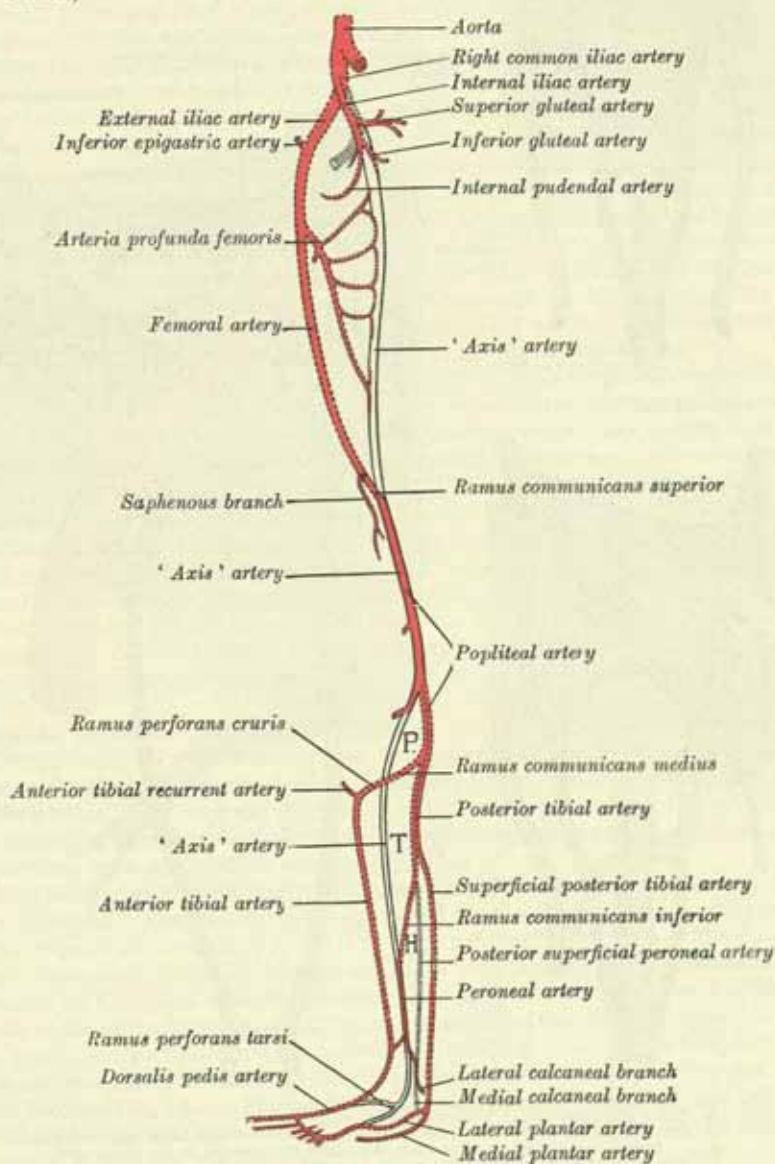


Later, the radial artery establishes a connexion with the main trunk at or near the site of origin of the ulnar artery and the upper portion of its original stem disappears to a large extent (see also p. 779). On reaching the hand the ulnar artery becomes linked up with the superficial palmar plexus, from which the superficial palmar arch is derived, while the median artery loses its distal connexions and becomes reduced to a very small vessel. The radial artery passes to the dorsal surface of the hand but, after giving off dorsal digital branches, it perforates the first intermetacarpal space and links up with the deep palmar arch.

The primary arterial trunk (fig. 187) or 'axis' artery of the lower limb arises from the dorsal root of the umbilical artery, and courses along the dorsal surface of the thigh, knee and leg; below the knee it lies between the tibia and the popliteus muscle, and in the leg between the crural interosseous membrane and the tibialis posterior muscle. It ends distally in a plantar network, and gives off a perforating artery which traverses the sinus tarsi and forms a dorsal network. The femoral artery passes along the ventral surface of the thigh, and opens up a new channel to the lower limb. It arises from a capillary plexus, connected proximally with the femoral branches of the external iliac artery, and distally with the axis artery. At the proximal margin of the popliteus the axis artery gives off a *primitive posterior tibial* and a *primitive peroneal branch*, which run distally on the dorsal surface of that muscle and on the tibialis posterior to gain the sole of the foot. At the distal border

of the popliteus the axis artery gives off a *perforating branch*, which passes ventrally between the tibia and the fibula and then runs downwards to the dorsum of the foot, forming the anterior tibial artery and the arteria dorsalis pedis. The primitive peroneal artery establishes one communication with the axis artery at the distal border of the popliteus and another in its course through the leg.*

FIG. 187.—A diagram to illustrate the general development of the arteries of the lower limb. The letter P indicates the position of the Popliteus; T that of the Tibialis posterior; and H that of the Flexor hallucis longus. (H. D. Senior.)



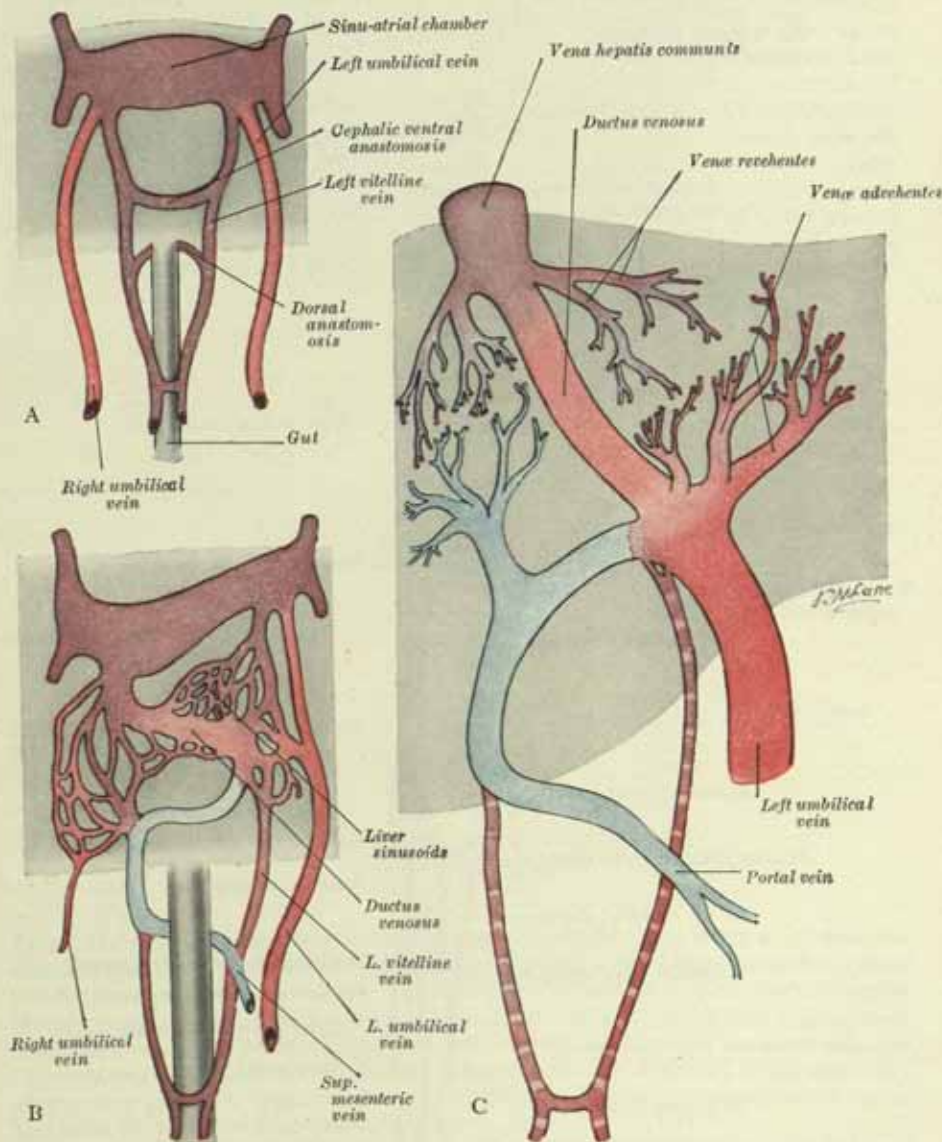
The femoral artery gradually increases in size, and coincidentally with this increase almost the whole of the axis artery, proximal to its communication with the femoral, disappears; the root of the axis artery, however, persists as the inferior gluteal artery and the arteria comitans nervi ischiadici.

The proximal parts of the primitive posterior tibial and primitive peroneal arteries fuse, but their distal parts remain separate. Ultimately large portions of the

* H. D. Senior, *Am. J. Anat.*, 25, 1919, and *Anat. Rec.*, 17, 1920

axis artery and of the primitive peroneal artery disappear, although a part of the former vessel is incorporated in the permanent peroneal artery. The changes are shown in greater detail in fig. 187.

FIG. 188.—Three stages in the development of the veins of the liver.



- A. Pink = umbilical veins; mauve = vitelline veins.
 B. Pink = umbilical veins and ductus venosus; mauve = vitelline veins and sinusoids of liver; blue = portions of vitelline veins later incorporated in the portal vein.
 C. Blue = portal vein; interrupted mauve = portions of vitelline veins which disappear completely; pink = left umbilical vein and ductus venosus.

The further development of the veins.—The principal veins of the embryo may be divided into two groups, visceral and parietal.

The visceral veins.—These include the two vitelline veins bringing the blood from the yolk-sac, and the two umbilical veins returning the blood from the placenta; these four veins run through the septum transversum, and open into the sinus venosus.

The vitelline veins run upwards, at first in front and subsequently one on each side of the digestive tube. A transverse anastomosis connects the two veins across the ventral surface of the tube, and beyond this they are connected to each other by two further anastomotic channels, one on the dorsal and the other on the ventral surface of the duodenal portion of the intestine, which is thus encircled by two venous rings forming the figure 8 (fig. 188, *A*). The portions of the vitelline veins within the septum transversum become surrounded by the trabeculae of the developing liver. The liver *sinusoids* develop as a plexus within the septum transversum and communicate freely with the vitelline and later the umbilical veins. The portions of the vitelline veins within the liver eventually lose their identity within the plexus of sinusoids. The umbilical veins, running headwards from the umbilicus in the somatopleure, traverse the septum transversum on their way to the sinus venosus. After a time the right umbilical vein entirely disappears, but the left umbilical vein, which retains for a period its direct connexion with the left horn of the sinus venosus, pours its blood into the liver sinusoids and so communicates with the vitelline circulation (fig. 188, *B*). In association with the establishment of the pulmonary circulation, venous channels develop which convey the blood from the left side of the liver to the right horn of the sinus venosus, where a large *common hepatic vein* now opens. The sinusoidal condition of the liver becomes condensed into a series of afferent vessels (*venae advehentes*) and a series of efferent vessels (*venae revehentes*) now leading to the common hepatic vein. In the process an oblique channel is differentiated from the liver sinusoids and conveys most of the blood brought by the umbilical vein direct to the common hepatic vein. This vessel is the *ductus venosus* (fig. 188, *C*) and it plays a very important part in the fetal circulation.

The superior mesenteric vein joins the left vitelline vein near the left extremity of the dorsal anastomosis. Later it is joined by the splenic vein, and the portal vein is thus established. Portions of the right and left vitelline veins disappear (fig. 188, *C*) and the portal vein is continued through the dorsal anastomosis, and the cephalic part of the right vitelline vein to the liver. The intrahepatic part of the right vitelline vein becomes the right branch of the portal vein, while the cephalic ventral anastomosis and the intrahepatic part of the left vitelline vein form its left branch. The (left) umbilical vein joins the left branch of the portal vein, to which the ductus venosus is also connected. Some of the blood conveyed to the liver by the umbilical vein passes through the left *venae advehentes*, but the great majority of it finds its way through the ductus venosus to the *vena hepatis communis* (which later forms the upper end of the inferior vena cava) and so to the right horn of the sinus venosus.

Somatic veins.—The venous drainage of the body-wall is effected at first by two large veins on each side, termed the *anterior* and *posterior cardinal veins*; the former drains the cephalic half of the embryo, and the latter the caudal half. These two veins unite to form a short vessel, termed the *duct of Cuvier*, which passes ventrally, lateral to the pleuropericardial canal (fig. 215), to open into the corresponding horn of the sinus venosus (fig. 182).

Owing to the rapid development of the head and brain the *anterior cardinal veins* become enlarged. They are further augmented by receiving the veins (*subclavian*) from the upper limb-buds, and so come to form the chief tributaries of the ducts of Cuvier; these ducts gradually assume an almost vertical position in consequence of the descent of the heart into the thorax. The right and left ducts of Cuvier are originally of the same diameter, and are sometimes termed the common cardinal veins. By the development of a transverse connexion (the *left brachiocephalic vein*) between the two anterior cardinal veins, the blood is carried across from the left to the right anterior cardinal (fig. 190). The portion of the right anterior cardinal vein between the left brachiocephalic and the azygos vein forms the upper part of the superior vena cava of the adult; the lower part of the latter vessel (i.e. below the entrance of the azygos vein) is formed by the right duct of Cuvier. Below the left brachiocephalic vein the left anterior cardinal vein and left duct of Cuvier atrophy, the former constituting the terminal part of the left superior intercostal vein, while the latter is represented by the ligament of the left vena cava and the oblique vein of the left atrium (fig. 190). The remainder of the left superior intercostal vein is developed from the upper end of the posterior cardinal vein and drains the second, third and, frequently, the fourth intercostal space. The oblique vein of the left atrium passes downwards across the back of the left atrium to open into the coronary

sinus, which, as already indicated, represents the persistent left horn of the sinus venosus. Right and left superior venæ cavæ are present in some animals, and are occasionally found in the adult human being.

The *inferior vena cava* of the adult is a composite vessel, and the precise mode of development of its postrenal segment is still somewhat uncertain. Its earliest forerunner is the posterior cardinal vein, which receives the venous drainage of the lower limb-bud and the pelvis and runs in the dorsal part of the mesonephric ridge, receiving tributaries from the body-wall (intersegmental veins) and from the mesonephros (figs. 189 to 193).

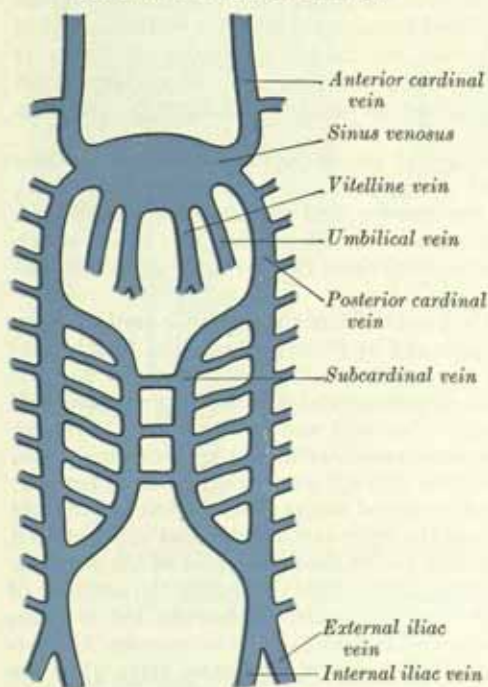
A second longitudinal vein, termed the *subcardinal vein*, forms in the ventrimedial part of the mesonephric ridge and becomes connected to the posterior cardinal vein by a number of vessels which traverse the medial part of the ridge. The two subcardinal veins communicate with each other by a *preaortic anastomosis*, which later constitutes that portion of the left renal vein which crosses in front of the abdominal aorta.

The establishment of a cross anastomosis between the iliac veins, which forms a large part of the left common iliac vein in the adult, results in the preponderance of the right over the left longitudinal veins and helps to account for the subsequent disappearance of the latter.

At its headward end the subcardinal vein receives the suprarenal vein on each side, but on the right side it comes into intimate relationship with the liver. An extension of the vessel takes place in a cephalic direction and meets and establishes continuity with a corresponding new formation which is growing tailwards from the vena hepatis communis. In this way on the right side a more direct route is established to the heart and the prerenal segment of the inferior vena cava is formed.

The enlargement of the metanephros thrusts the posterior cardinal vein out of its course and the venous drainage of the mesonephric ridge is taken over by the

FIG. 189.—A diagram to show an early stage in the development of the abdominal veins. Compare with figs. 191 and 192.

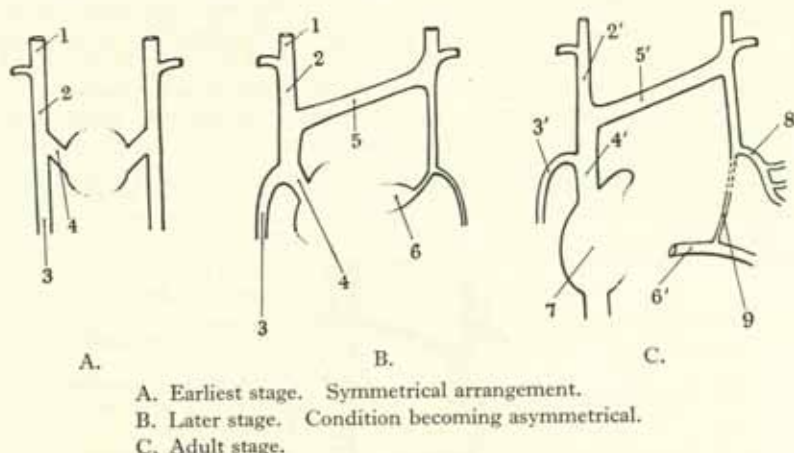


subcardinal vein. At the same time new longitudinal channels form which take over the intersegmental venous drainage, and the whole of the posterior cardinal vein disappears with the exception of its extreme cephalic and caudal ends. These new channels are four in number on each side (fig. 191), but, so far as is known at the present time, only two of them persist as large vessels in the adult: (1) A longitudinal channel forms dorsolateral to the aorta and lateral to the sympathetic trunk and its branches, and takes over the intersegmental venous drainage from the posterior cardinal vein. This is the *thoraco-lumbar line* (of Reagan). (2) A second channel is formed, also dorsolateral to the aorta but medial to the sympathetic trunk and the branches which it sends to the preaortic plexuses. This vessel constitutes the *azygos line* and, in turn, it takes over the intersegmental venous drainage from the thoraco-lumbar line. The intersegmental veins now, for the first time, reach their longitudinal channel by passing deep (medial) to the sympathetic trunk, the relationship which the

lumbar and intercostal veins exhibit in the adult. At its cephalic end the azygos line joins the persistent cephalic part of the posterior cardinal vein. (3) Two *subcentral veins* are laid down directly dorsal to the aorta in the interval between the origins of the paired intersegmental arteries. These veins communicate freely with each other

and with the azygos lines, and these connexions ultimately form the retro-aortic parts of the left lumbar veins and of the hemi-azygos veins. (4) The *supracardinal*

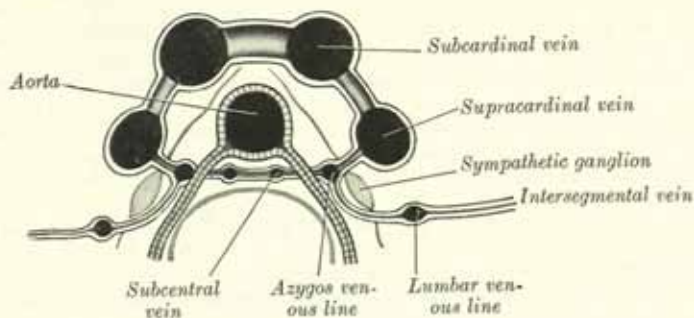
FIG. 190.—A diagram to illustrate the mode of development of the superior vena cava.



1=primitive head vein; 2=anterior cardinal vein; 2'=right brachiocephalic vein; 3=posterior cardinal vein; 3'=vena azygos; 4=right duct of Cuvier; 4'=superior vena cava; 5=transverse anastomosis; 5'=left brachiocephalic vein; 6=left horn of sinus venosus; 6'=coronary sinus; 7=right atrium; 8=left superior intercostal vein; 9=oblique vein of left atrium.

veins* are laid down lateral to the aorta and lateral to the sympathetic trunk and its branches to the preaortic plexuses, which therefore intervene between them and the azygos lines. These veins communicate caudally with the iliac veins and cephalically with the subcardinal veins in the neighbourhood of the preaortic intersubcardinal anastomosis. In addition, the supracardinal veins communicate freely with each other through the medium of the azygos lines and the subcentral veins. The most

FIG. 191—Scheme of a composite transverse section to show the relative positions of some of the longitudinal somatic veins in the lumbar region and the anastomotic vessels by which they are connected, after the disappearance of the posterior cardinal veins. (After Gladstone.)



cranial of these connexions, together with the supra-subcardinal and intersubcardinal anastomosis, complete a venous ring around the aorta below the origin of the superior mesenteric artery, termed the '*renal collar*' † (fig. 191).

The right supracardinal vein persists and forms the greater part of the postrenal segment of the inferior vena cava, the continuity of the vessel being maintained by the persistence of the anastomosis between the right supracardinal and the right subcardinal in the '*renal collar*.' The left supracardinal disappears, but the portion of

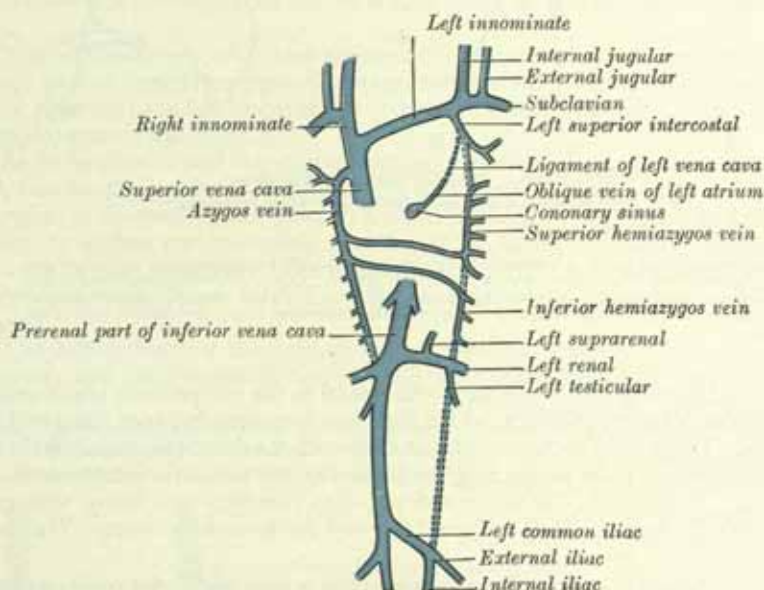
* According to some authorities, the supracardinal vein is identical with the thoraco-lumbar line.

† S. S. Huntington and C. F. W. McClure, *Anat. Rec.*, 17, 1920.

the 'renal collar' formed by the left supra-subcardinal anastomosis in part persists in the left renal vein.

The inferior vena cava is therefore formed, from below upwards, by (1) the right supracardinal vein, (2) an anastomosis between the right supra- and subcardinal veins, (3) the right sub-cardinal vein, (4) a new formation which connects the right subcardinal and the common hepatic veins, and (5) the common hepatic vein.* It should be noted that only the supracardinal part of the inferior vena cava receives the intersegmental venous drainage, and that the postrenal segment of the inferior vena cava is on a plane which lies dorsal to the plane of the prerenal segment. On this account the right phrenic, suprarenal and renal arteries, which represent

FIG. 192.—A diagram showing the completion of the development of the parietal veins.



persistent mesonephric arteries, pass behind the inferior vena cava while the testicular (or ovarian), which has a similar developmental origin, passes in front of it.

In some animals the right posterior cardinal vein constitutes a large part of the postrenal segment of the inferior vena cava. In these cases the right ureter, on leaving the kidney, passes medially dorsal to the vessel and then, curving round its medial side, crosses its ventral aspect. Very rarely a similar condition is found in the human subject, and indicates persistence of the right posterior cardinal vein and failure of the right supracardinal to play its normal part in the development of the vessel.

Summary of the history of the embryonic abdominal and thoracic longitudinal somatic veins.

(1) The terminal part of the posterior cardinal vein on the left side forms the distal part of the left superior intercostal vein; on the right side its cephalic end persists and forms the terminal portion of the vena azygos.

(2) The caudal part of the subcardinal vein is partly incorporated in the testicular (or ovarian) vein (McClure and Butler †) and partly disappears. The cephalic end of the right subcardinal vein is incorporated in the inferior vena cava and forms the right suprarenal vein. The left subcardinal vein, cephalic to the intersubcardinal anastomosis, is incorporated in the left suprarenal vein. The renal and testicular (ovarian) veins on both sides join the supracardinal-subcardinal anastomosis. On the left side this is connected directly to the portion of the inferior vena cava which is of subcardinal value through an intersubcardinal anastomosis.

(3) The right supracardinal vein forms the postrenal segment of the inferior vena cava. The left supracardinal vein disappears entirely.

(4) The right azygos line persists in its thoracic portion to form all but the terminal part of the vena azygos. Its lumbar part can usually be identified as a small vessel

* For a detailed account, see R. J. Gladstone, *J. Anat., Lond.*, **64**, 1929.

† C. F. W. McClure and E. G. Butler, *Amer. J. Anat.*, **35**, 1925.

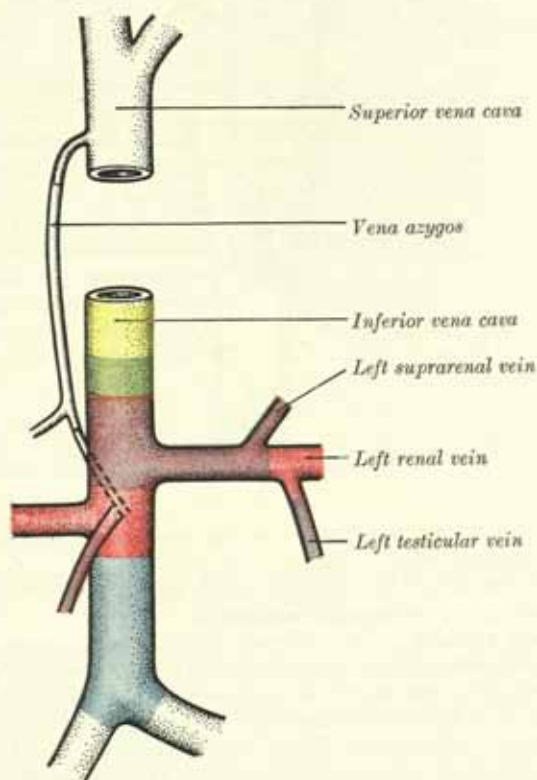
which leaves the vena azygos on the body of the twelfth thoracic vertebra and descends on the vertebral column, deep to the right crus of the diaphragm, to join the posterior aspect of the inferior vena cava at the upper end of its postrenal segment. The left azygos line forms the hemiazygos veins.

(5) The subcentral veins give rise to the retro-aortic parts of the left lumbar veins and of the hemiazygos veins.

(6) The later history of the thoraco-lumbar lines is uncertain but some authorities regard them as identical with the supracardinal veins.

The development of the *venous sinuses of the dura mater* has a very complicated history which need not be set out here in detail but which was worked out by Streeter.* It will suffice to state that the primary blood-vessels of the head consist of a close-meshed capillary plexus which is drained by a pair of veins, named the *primary head veins*. Each primary head vein begins on the diencephalon, and courses along the side of the brain running medial to the trigeminal ganglion and, at first, lateral to the auditory vesicle; on reaching the vagus nerve it turns sharply caudally and opens into the duct of Cuvier. The part of the vein which is caudal to the vagus nerve is the anterior cardinal vein, the cephalic portion of which forms the internal

FIG. 193.—Diagram of the constituent parts of the inferior vena cava.



The supracardinal segment is shown in blue: the supracardinal-subcardinal segment in pink: the subcardinal segment in mauve: the subcardinal-hepatic segment in green: the hepatic segment in yellow.

The persistent part of the right posterior cardinal vein is shown in stipple, at the upper end of the vena azygos.

jugular vein, while its caudal portion has already been described (p. 175). At a later stage the greater part of the original capillary plexus assumes the form of three secondary plexuses—anterior, middle and posterior, associated respectively with the forebrain, the tectum and pons, and the medulla oblongata. The stems which connect these plexuses to the primary head vein undergo a series of changes but finally take part in the formation of the transverse and sigmoid sinuses.

At an early stage the cephalic end of the primary head vein receives the veins from the developing eye and this portion persists to form the cavernous sinus.

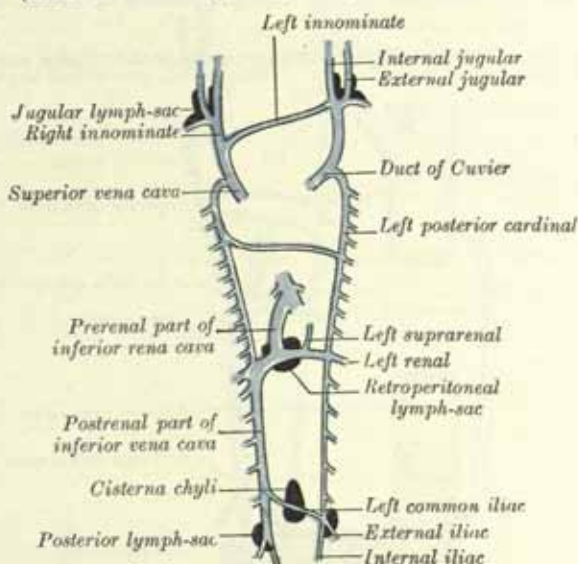
Between the growing cerebral hemispheres extensions of the anterior and middle

* G. L. Streeter *Amer. J. Anat.*, 18, 1915.

plexuses of both sides meet and form the *sagittal plexus*, a curtain of capillary veins which hangs down in the position of the future falx cerebri. Along the dorsal margin of this curtain the superior sagittal sinus is evolved, and this sinus usually joins the right transverse sinus; along the ventral free edge of the curtain the inferior sagittal sinus and the straight sinus are formed, the latter passing into the left transverse sinus.

The external jugular vein at first drains the region behind the ear (posterior auricular) and enters the anterior cardinal as a lateral tributary. A group of veins from the face and lingual region converge to form a common vein, termed the *linguofacial*, which also ends in the anterior cardinal vein. Later, cross communications develop between the external jugular and the linguofacial, with the result that the posterior group of facial veins is transferred to the external jugular vein. The

FIG. 194.—A scheme showing the relative positions of the primary lymph-sacs.
(Based on the description given by Florence Sabin.)



cephalic vein is, for a time, a tributary of the external jugular vein, but is later diverted into the axillary vein.

The fetal circulation and the changes which take place in the circulation after birth are described in the section on Angiology.

The lymphatic system.—Two different views are still current as to the initial stages in the development of the lymphatic system. According to the view put forward by Huntington and McClure lymphatic spaces appear as clefts in the mesenchyme, and their lining cells take on the characters of endothelium. These spaces form capillary plexuses from which certain lymph-sacs, to be noted later, are derived. The connexions of the lymphatic with the venous system are entirely secondary. According to Sabin, however, the earliest lymph vessels arise as capillary offshoots from the endothelium of the veins, which form capillary plexuses. These plexuses lose their connexions with the venous system and become confluent to form lymph-sacs. The balance of the evidence suggests that the lymphatic system originates independently of the venous system and only acquires connexions with it at a later stage.

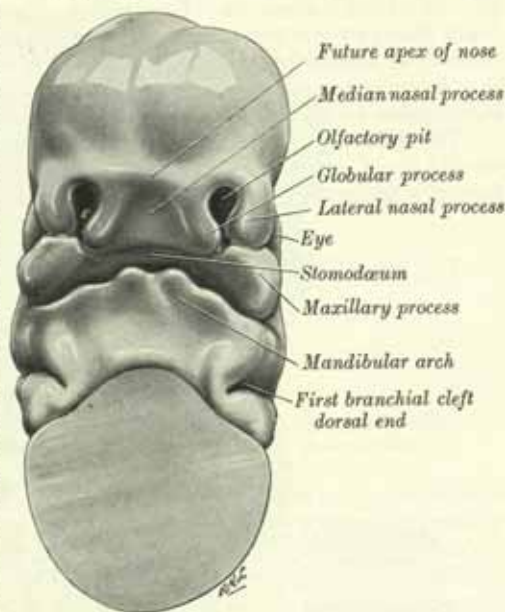
In the human embryo the lymph-sacs from which the lymph vessels are derived are six in number; two paired (the jugular and the posterior lymph-sacs) and two unpaired (the retroperitoneal and the cisterna chyli). In lower mammals an additional pair (the subclavian) is present, but in the human embryo these are merely extensions of the jugular sacs.

The position of the sacs is as follows (fig. 194): (1) the jugular, the first to appear, at the junction of the subclavian vein with the anterior cardinal; (2) the posterior, at the junction of the iliac vein, with the posterior cardinal; (3) the retroperitoneal,

in the root of the mesentery near the suprarenal glands; (4) the cisterna chyli, opposite the third and fourth lumbar vertebræ. From the lymph-sacs the lymph vessels bud out along fixed lines corresponding more or less closely with the course of the embryonic blood-vessels, but many arise *de novo* in the mesenchyme and establish connexions with existing vessels. In the body-wall and in the wall of the intestine,* the deeper plexuses are the first to be developed; by continued growth of these the vessels in the superficial layers are gradually formed. The thoracic duct is, phylogenetically, a bilateral structure. In man it comprises the caudal part of the right vessel, a transverse anastomosis and the cephalic part of the left vessel. According to Sabin it is formed from anastomosing outgrowths from the jugular sac and cisterna chyli. At its connexion with the cisterna chyli it is at first double, but the vessels soon join. Numerous valves are laid down in the duct during the fifth month, but many of them disappear prior to birth. Those which persist are formed in situations where the duct may be subjected to pressure, e.g. where it is crossed by the œsophagus and the aortic arch.

All the lymph-sacs except the cisterna chyli are, at a later stage, divided up by a number of slender connective tissue bridges. Later they are invaded by lymphocytes and transformed into groups of lymph glands, the lymph sinuses representing portions of the original cavity of the sac. The lower portion of the cisterna chyli is similarly converted, but its upper portion remains as the adult cisterna.

FIG. 195.—The head of a human embryo in the sixth week. Ventral aspect. (Drawn from a reconstruction model made by Karl Peter.)



THE DEVELOPMENT OF THE DIGESTIVE AND RESPIRATORY APPARATUS

The **mouth** is developed partly from the stomodæum, and partly from the floor of the cephalic portion of the fore-gut. By the growth of the head-end of the embryo and the formation of the head-fold, the pericardial area and the bucco-pharyngeal or oral membrane come to lie on the ventral surface of the embryo (p. 82). With the further expansion of the brain, and the bulging of the pericardium, the oral membrane comes to lie at the bottom of a depression bounded by these two prominences. This depression constitutes the *stomodæum* or *primitive mouth* (fig. 89). It is lined with ectoderm, and is separated from the cephalic end of the fore-gut by the oral membrane, which is formed by the apposition of the stomodæal ectoderm with the fore-gut endoderm; at the end of the fourth week the membrane disappears and a communication is established between the primitive mouth and the cephalic end of the fore-gut or future pharynx. No vestige of the membrane is found in the adult; and the communication just mentioned must not be confused with the permanent oro-pharyngeal isthmus. The epithelium of the lips and gums and the enamel of the teeth are ectodermal in origin, being formed from the walls of the stomodæum, but the epithelium of the tongue, which is developed in the floor of the mouth and pharynx, is derived from the endoderm.

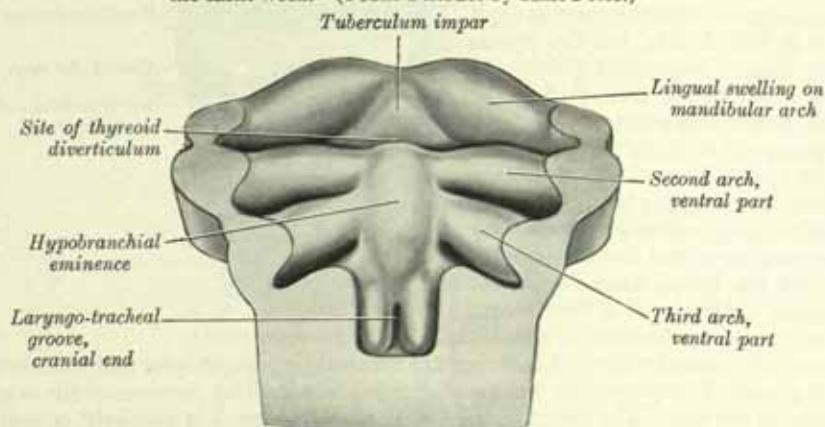
The visceral arches grow in a ventral direction and come to lie between the

* G. Heuer, *Amer. J. Anat.*, 9, 1909.

stomodæum and the pericardium; with the completion of the mandibular arch and the development of the maxillary processes (p. 111), the opening of the stomodæum assumes a pentagonal form, bounded on its cephalic side by the frontonasal process, caudally by the mandibular arches, and laterally by the maxillary processes (fig. 195). With the inward growth and fusion of the palatine processes (figs. 125 and 127), the stomodæum is divided into a nasal and a buccal part. Along the free margins of the processes bounding the mouth cavity there appears a shallow groove, termed the *primary labial groove*. The ectoderm in the floor of this groove thickens and invades the underlying mesoderm. The central cells of this ingrowth soon degenerate and break down so that the primary labial groove becomes deepened. It may now be termed the *alveolo-labial groove*, for its inner wall contributes to the formation of the alveolar processes of the maxillæ and the mandible, while its outer wall forms the lips and cheeks.

The **salivary glands** arise from the epithelial lining of the mouth. The *parotid gland* can be recognised in human embryos 8 mm. long as an elongated furrow running dorsally from the angle of the mouth between the mandibular arch

FIG. 196.—The floor of the pharynx of a human embryo at the beginning of the sixth week. (From a model by Karl Peter.)

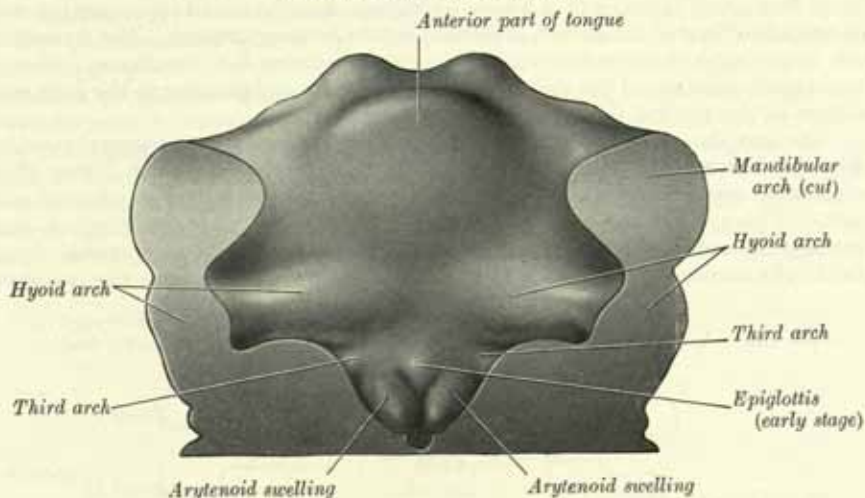


and the maxillary process. The groove, which is converted into a tube, loses its connexion with the epithelium of the mouth, except at its anterior end, and grows dorsally into the substance of the cheek. The tube persists as the parotid duct and its blind end proliferates to form the gland. Subsequently the size of the oral fissure is reduced, and the duct opens thereafter on the inside of the cheek at some distance from the angle of the mouth. The *submandibular gland* is present in human embryos, 13 mm. long, as an epithelial outgrowth from the floor of the alveolo-lingual groove (below). It increases rapidly in size by giving off numerous branching processes which later acquire lumina. At first the connexion of the submandibular outgrowth with the floor of the mouth lies at the side of the tongue, but the edges of the groove in which it opens come together, from behind forwards, and form the tubular part of the submandibular duct. As a result the orifice of the duct is shifted forwards till it comes to lie below the tip of the tongue, close to the median plane (Frazer). The *sublingual gland* arises in embryos about 20 mm. long as a number of small epithelial thickenings in the alveolo-lingual groove and on the lateral side of the groove which later closes to form the submandibular duct.

The tongue.—Before the visceral arches meet one another at their ventral ends, a small median elevation, named the *tuberculum impar*, appears in the entodermal floor of the pharynx, and it subsequently becomes incorporated in the anterior part of the tongue. A little later two oval *lingual swellings* appear on the entodermal aspect of the mandibular arches. They meet each other in front, and caudally they converge on the tuberculum impar, with which they fuse (figs. 196 and 197). A sulcus forms along the ventral and lateral margins of this elevation and deepens to form the *alveolo-lingual groove*, while the elevation constitutes the anterior or buccal part of the tongue.

Caudal to the tuberculum impar, a second median elevation, termed the *hypo-branchial eminence* (Frazer) [*copula* of His], forms in the floor of the pharynx, and it receives the ventral ends of the fourth, the third and, later, the second visceral

FIG. 197.—The floor of the pharynx of a human embryo, about six weeks old. (From a model by Karl Peter.)



arches. A transverse groove separates off the caudal portion of the eminence to form the epiglottis, while its ventral portion approaches the tongue rudiment, spreading ventrally in the form of a V, and blends with it to constitute the posterior or pharyngeal part of the tongue. In the process the third arch elements grow over and bury the elements of the second arch, excluding it from the tongue. As a result the mucous membrane of the pharyngeal part of the tongue receives its sensory supply from the glossopharyngeal, the nerve of the third arch. In the adult the union of the anterior and posterior parts of the tongue is marked by the V-shaped sulcus terminalis, the apex of which is at the foramen cæcum, a pit-like depression produced at the time of fusion of the constituent parts of the tongue, but also marking the site of the outgrowth of the median rudiment of the thyreoid gland.

At first the tongue consists of a mass of mesoderm covered on its free surface by entoderm. During the second month the occipital myotomes migrate from their original position on the lateral aspect of the myelencephalon and invade the tongue to form its musculature. They pass ventrally round the wall of the pharynx to reach its floor and they are accompanied, necessarily, by their nerve of supply (the hypoglossal nerve), which therefore crosses superficial to both the internal carotid (dorsal aorta) and the external carotid arteries.

The composite character of the tongue is indicated by its adult innervation. The anterior or buccal part receives sensory branches from (a) the lingual nerve, which is derived from the (post-trematic) nerve of the first arch (mandibular nerve); and (b) the chorda tympani, which is the pre-trematic nerve of the first arch. The posterior or pharyngeal part of the tongue receives its innervation from the glosso-pharyngeal, which is the nerve of the third arch. The muscles of the tongue are myotomic in origin and receive their nerve-supply from the hypoglossal nerve, which is serially homologous with the anterior nerve-roots of the spinal nerves.

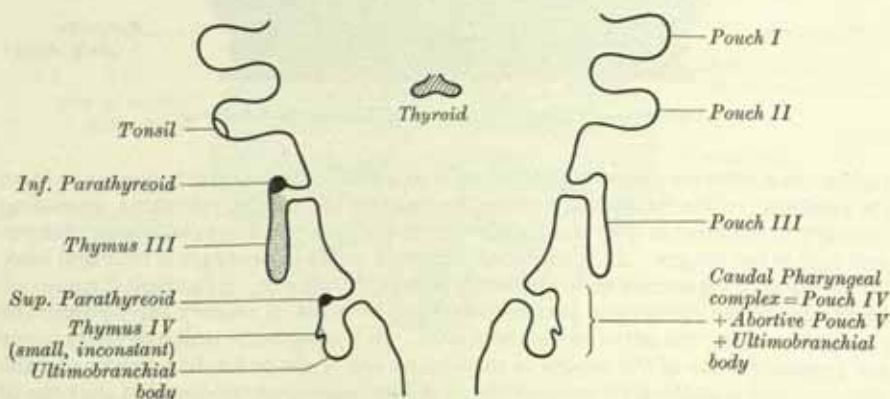
The **thyreoid gland** is first indicated in embryos of about 20 somites, as a median thickening of the entoderm in the floor of the pharynx between the levels of the first and second pharyngeal pouches and immediately overlying the aortic sac.* This area is later evaginated to form a median diverticulum, which appears in the latter half of the fourth week in the furrow immediately caudal to the tuberculum impar (fig. 196). It grows caudally as a tubular duct which bifurcates and subsequently divides into a series of double cellular plates, from which the isthmus and portions

* C. L. Davis, *Contr. Embryol. Carneg. Instn.*, 15, 1923.

of the lateral lobes of the thyreoid gland are developed. The *primary thyreoid follicles* differentiate by reorganisation and proliferation of the cells of these plates. *Secondary follicles* subsequently arise by budding and subdivision.* The claim that the fourth pharyngeal pouches contribute thyreoid tissue to the lateral lobes of the gland is disputed and seems unlikely on the grounds of comparative embryology. The connexion of the median diverticulum with the pharynx is termed the *thyreoglossal duct*; it is obliterated at a very early stage, but the site of its connexion with the epithelial floor of the mouth is marked by the foramen cæcum. The pyramidal lobe is probably a secondary extension upwards from the developing isthmus. Occasionally portions of the thyreoglossal duct persist and give rise to the formation of cysts in the median line of the neck.

The **tonsils** are developed from the parts of the second pharyngeal pouches which lie between the tongue and the soft palate. The entoderm lining these pouches grows into the surrounding mesoderm in the form of a number of solid buds. These buds are excavated by the degeneration and shedding of their central cells, and by this means the tonsillar fossulae and crypts are formed. Lymphoid cells accumulate around the crypts, and are grouped to form the lymphoid

FIG. 198.—A scheme showing the development of the branchial epithelial bodies.



follicles. A slit-like fissure, which lies immediately above the tonsil and is termed the *supratonsillar cleft* (p. 1383), is a remnant of the second pharyngeal pouch.

The **thymus** is derived from the entoderm of the ventral part of the third pharyngeal pouch on each side (fig. 198). It cannot be recognised prior to the differentiation of the inferior parathyreoid glands (*vide infra*)—which occurs when the embryo is 10–12 mm. long—but thereafter it is represented by two flask-shaped diverticula which soon become solid cellular masses and grow caudally into the surrounding mesenchyme. In front of the aortic sac (p. 168) the two thymic rudiments meet and are subsequently united by connective tissue, but the rudiments themselves never fuse. The connexion with the third pouch is soon lost, but the stalk may persist for some time as a solid, cellular cord.

The development of thymic tissue from the ventral recess of the fourth pharyngeal pouch occurs in a proportion of embryos,† although this has been denied by some authorities.‡ Thymic tissue developing from this site is usually found outside the thyreoid gland in close association with the superior parathyreoid gland. An ectodermal contribution, probably of placodal origin, to the thymus undoubtedly occurs in some mammals but the presence of a similar contribution in man cannot be regarded as proved.§

Vascularised mesenchyme, including lymphoblasts, invades the cellular mass of the entodermal thymus and it becomes partially lobulated. The cells of the cytotreticulum and the concentric corpuscles of the thymus are entodermal in origin.

* E. H. Norris, *Amer. J. Anat.*, **20**, 1916.

† J. H. Van Dyke, *Anat. Rec.*, **78**, 1941.

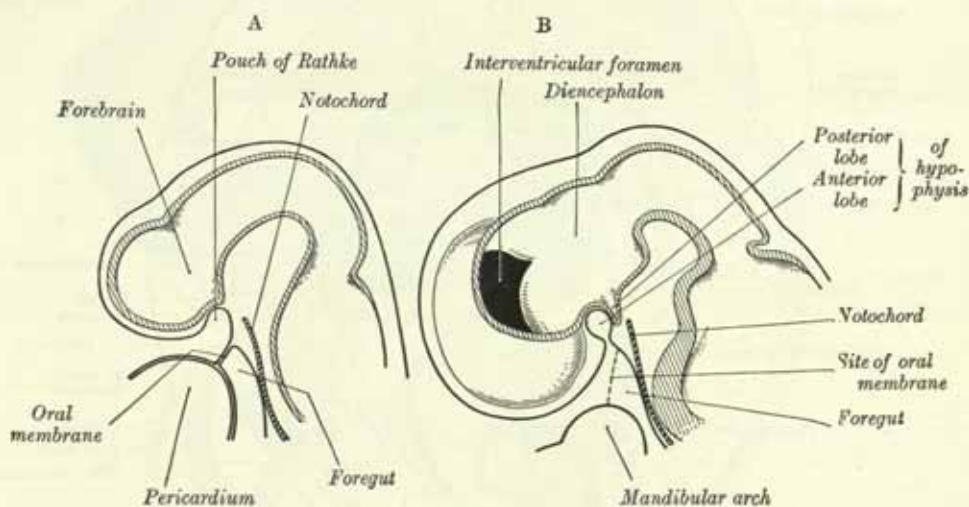
‡ L. G. Weller, *Contr. Embryol. Carneg. Instn.*, **24**, 1933, and E. H. Norris, *ibid.*, **27**, 1938.

§ F. D. Garrett, *loc. cit.*

At birth the thymus is large relative to the weight of the body. Its absolute weight increases in the first two years after birth but its relative weight decreases. There is little change thereafter until about the seventh year when rapid growth again occurs to reach a maximum size at about eleven years. After this it begins to decline to an adult figure which is very variable but averages 12–15 grams. In old age the gland shrinks still further, especially after wasting diseases. For this and other reasons it is rarely identifiable after preservation in the aged cadaver.*

The **parathyreoid glands** are also derivatives of the pharyngeal endoderm. Prior to the appearance of the thymic rudiment from the third pharyngeal pouch, the epithelium on the dorsal aspect of the pouch and in the region of its duct-like connexion with the cavity of the pharynx becomes differentiated and can be recognised as the primordium of the *inferior parathyreoid gland*, owing to the fact that its cells stain more lightly than the other endodermal cells lining the pouch. Although the connexion between the pouch and the pharynx is soon lost, the connexion between the thymic and parathyreoid rudiments persists for some time, with the result that the latter is drawn caudally with the developing thymus. The *superior*

FIG. 199.—Schematic sagittal sections of heads of early embryos to show first stages in the development of the hypophysis.



parathyreoid glands develop in a similar manner from the dorsal recess of the fourth pharyngeal pouches.

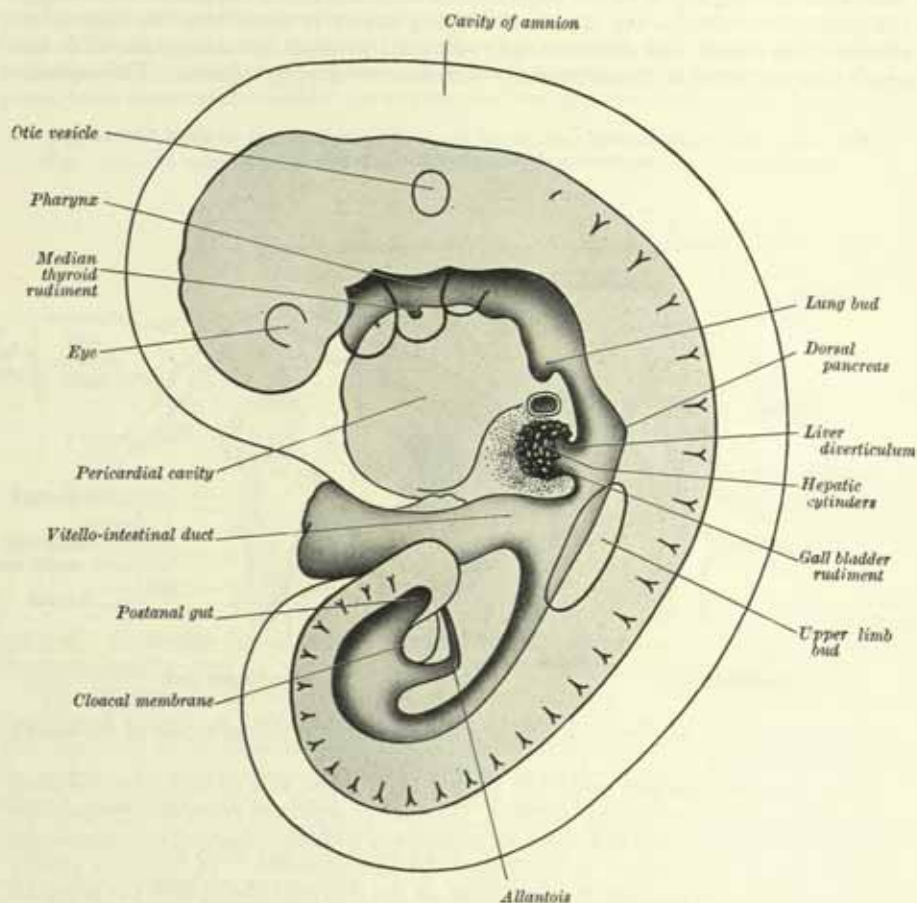
The **ultimobranchial body** has already been noted as a diverticulum forming part of the caudal pharyngeal complex. The latter separates from the ectoderm in the fourth branchial cleft and loses its connexion with the pharynx by attenuation and rupture of the ductus pharyngobranchialis communis. It becomes closely associated with the expanding lateral lobe of the thyroid gland, with the superior parathyreoid (parathyreoid IV) component of the complex lying dorsally and outside the thyroid gland. The remainder of the complex, which includes the ultimobranchial body and possibly some vestiges of the ventral recess of the fourth pharyngeal pouch and of the transitory fifth pharyngeal pouch, is enveloped by the thyroid gland. Its fate is disputed but it probably degenerates in this situation. The claim that it gives origin to thyroid tissue cannot be regarded as proved.

The **hypophysis** consists of an anterior and a posterior lobe; the former is derived from the ectoderm of the stomodæum, the latter from the neur ectoderm of the floor of the fore-brain. Previous to the rupture of the oral membrane a pouch-like recess is present in the ectodermal lining of the roof of the stomodæum. This recess (*pouch of Rathke*) (fig. 199, A) is the rudiment of the anterior lobe of the hypophysis; lying immediately ventral to the cephalic border of the oral membrane, it extends upwards in front of the cephalic end of the notochord, and is in contact with the under surface of the fore-brain. It is

* G. Keynes, *Brit. med. J.*, 2, 1954.

then constricted off by the surrounding mesenchyme to form a closed vesicle, but remains for a time connected to the ectoderm of the stomodæum by a solid cord of cells, which can be traced down the posterior edge of the nasal septum. Masses of epithelial cells form on each side and in the ventral wall of the vesicle, and by the growth of a stroma from the mesenchyme the development of the anterior lobe of the hypophysis is completed. A canal (*craniopharyngeal canal*), which sometimes runs from the anterior part of the hypophyseal fossa of the sphenoid bone to the under surface of the skull, is said to mark the original position of Rathke's pouch; *

FIG. 200.—The digestive tube of a human embryo with 29 paired somites. (End of fourth week.) (G. L. Streeter, *Contr. Embryol. Carneg. Instrn.*, 30, 1942.) ($\times \text{E. } 25$.)



Note.—This embryo has a crown-rump length of 3.4 mm. and its age is estimated at 27 days.

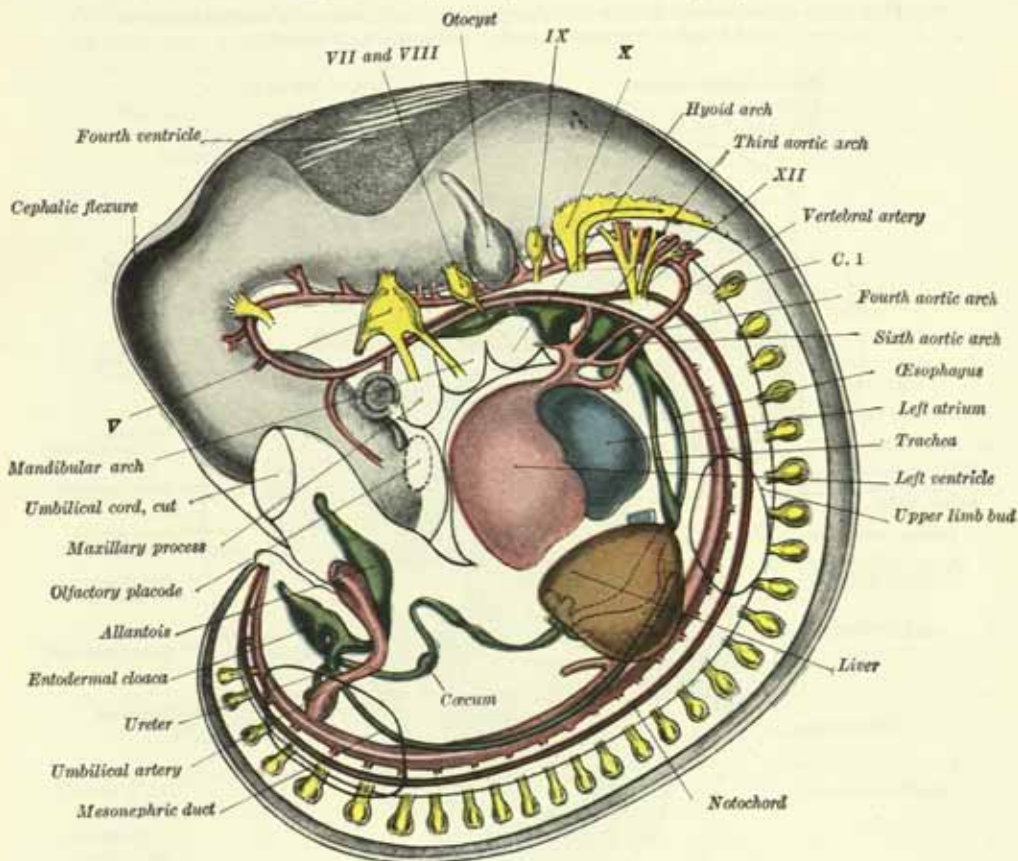
and traces of the stomodæal end of the pouch are occasionally present at the junction of the septum of the nose with the palate (Frazer). Just behind Rathke's pouch a hollow diverticulum grows towards the mouth from the floor of the diencephalon (fig. 199, B). This neural outgrowth forms a funnel-shaped sac, the walls of which increase in thickness so as to obliterate the contained cavity except at its upper end, where it persists as the *infundibular recess* of the third ventricle. Formed in this way the *posterior lobe* of the hypophysis becomes invested by the anterior lobe, which extends dorsally on each side of it. In addition, the anterior lobe gives off two processes from its ventral wall which grow along the infundibulum and fuse to surround

* It has recently been shown that the craniopharyngeal canal is a secondary formation, caused by the growth of blood-vessels, and is quite unconnected with the stalk of the anterior lobe (L. B. Arey, *Anat. Rec.*, 103, 1949).

it, coming into relation with the tuber cinereum and constituting the *tuberal portion* of the hypophysis. The original cavity of the stomodæal diverticulum remains as a cleft and can be identified readily in sagittal sections through the gland in the adult. The dorsal wall of the stomodæal part, which remains thin, fuses with the adjoining part of the posterior lobe and forms the *pars intermedia*. In some of the lower animals the posterior lobe contains nerve-cells and nerve-fibres, but in man and the higher vertebrates it consists only of neuroglial tissue.

A small entodermal diverticulum, named *Seessel's pouch*, projects towards the brain from the cephalic end of the fore-gut, close to the oral membrane. In some

FIG. 201.—A human embryo of 7 mm. greatest length. Fifth week. Left lateral aspect. (After Peter Thompson.)



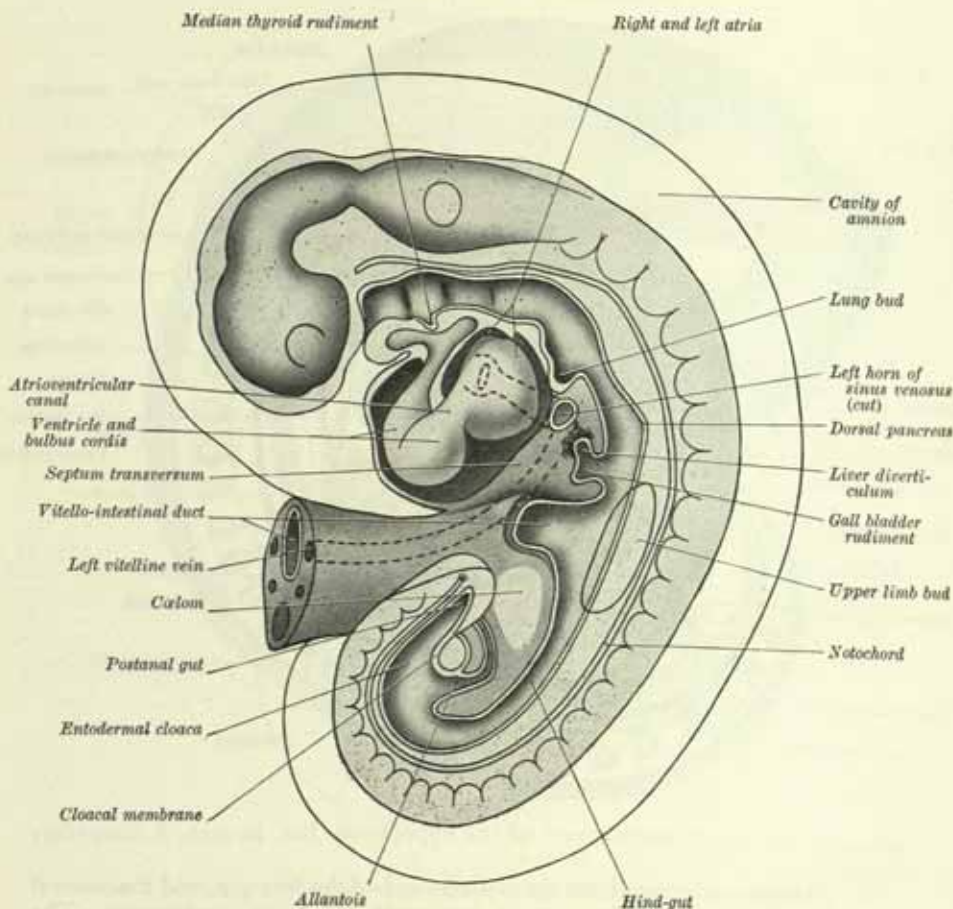
marsupials this pouch forms a part of the hypophysis, but, in man, it disappears entirely.

The **pharynx** is formed from the cephalic end of the fore-gut, and the visceral arches and pharyngeal pouches play an important part in its development. The entodermal aspect of the mandibular arch in its dorsal part contributes to the formation of the lateral wall of the nasal pharynx in front of the orifice of the auditory tube. The ventral end of the first pouch becomes obliterated, but its dorsal end persists and deepens as the head enlarges. It remains in close relationship with the ectoderm of the dorsal end of the first cleft (p. 116) and, together with the adjoining lateral part of the pharynx and dorsal part of the second pharyngeal pouch, constitutes the *tubotympanic recess*, which forms the tympanic cavity and the auditory tube (p. 151). The site of the second arch is partly indicated by the palato-glossal arch, but its dorsal end is separated from its ventral end by the forward growth of the third arch, which obliterates the intermediate part (Frazer). It is believed that the site of the second pharyngeal pouch is represented by the supratonsillar cleft, around which the tonsil is developed. The third arch forms the lateral glosso-epiglottic fold, and its dorsal end takes part in the formation of the floor of the auditory tube

(Frazer). The ventral ends of the fourth arches fuse with the posterior part of the hypobranchial eminence and so contribute to the formation of the epiglottis (p. 183). The adjoining portion becomes connected to the arytenoid swelling and may be identified in the aryepiglottic fold.

After the caudal portion of the hypobranchial eminence has been separated from the dorsal part of the tongue (p. 183), it is in continuity with two linear ridges which appear in the ventral wall of the pharynx, the whole forming an inverted U, regarded by His as an independent formation and called by him the *furcula*. Frazer identifies these vertical ridges as the sixth arches, placed very obliquely owing to the shortness of the pharyngeal floor compared with the greater extent of its roof. The contained groove of the *furcula* is carried downwards on the ventral wall of the fore-gut as the

FIG. 202.—A composite diagram of a graphic reconstruction of a human embryo at the end of the fourth week. (After G. L. Streeter.)



The alimentary canal and its outgrowths are shown in median section. The brain is shown in outline, but the spinal medulla is omitted. The heart is shown in perspective, the left horn of the sinus venosus having been divided. The somites are indicated in outline.

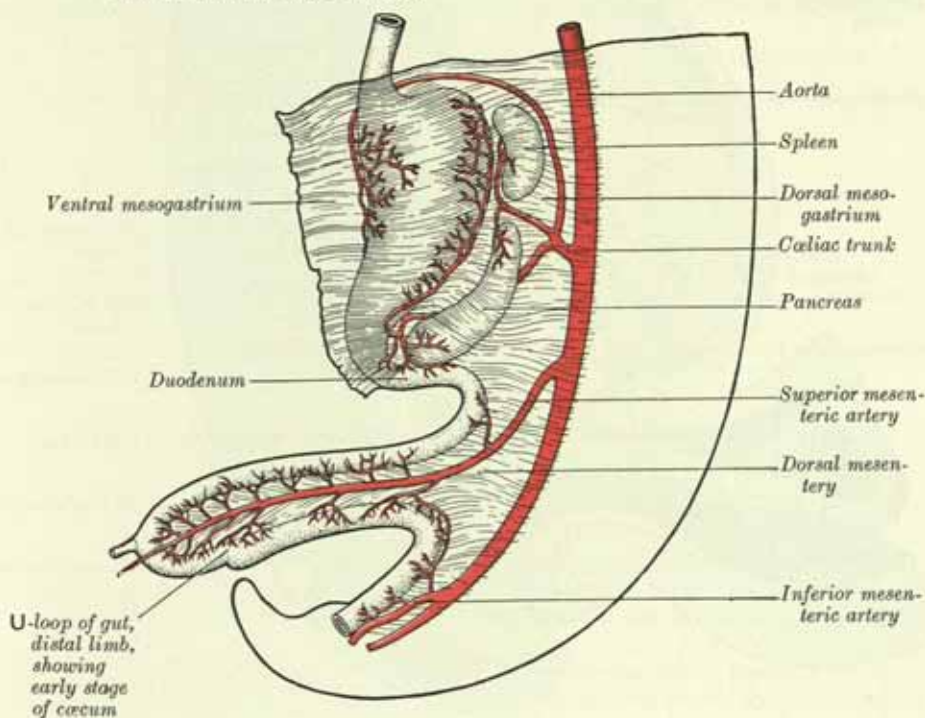
laryngotracheal groove, from which the lower part of the larynx, the trachea, bronchi and lungs are developed (p. 200). At the cephalic end of the groove paired arytenoid swellings arise which convert the slit-like upper aperture of the respiratory system into a T-shaped opening. The aryepiglottic folds can be recognised at this stage extending from the arytenoid swellings to the epiglottis.

The further development of the digestive tube.—The portion of the fore-gut which succeeds the pharynx remains tubular, and is elongated to form the œsophagus. At the end of the fourth or the beginning of the fifth week the stomach can be recognised as a fusiform dilation (fig. 200), and beyond this the gut opens into the yolk-sac; this opening is at first wide (fig. 181), but by the fifth week it has become narrowed

into a tubular stalk (the *vitelline* or *vitello-intestinal duct*), (fig. 200), which soon loses its connexion with the digestive tube (fig. 201). At this stage the stomach is placed in the median plane, and ventrally it is separated from the pericardium by the septum transversum (p. 86), which extends ventrally on to the cephalic side of the vitello-intestinal duct. Dorsally, the stomach is related to the dorsal aorta and, owing to the presence of the pleuroperitoneal canals on each side, it is connected to the body-wall by a short dorsal mesentery, termed the *dorsal mesogastrium* (fig. 203). This mesentery is directly continuous with the dorsal mesentery of the gut. The liver develops as a hollow diverticulum from the ventral aspect of the fore-gut and grows headwards into the substance of the septum transversum (fig. 200), and it is this part of the latter which is sometimes termed the *ventral mesogastrium*.

In the human embryo, at the 10 mm. stage, the curvatures of the stomach are defined. Growth proceeds more actively along the dorsal border of the viscus; its convexity is notably increased and the rudiment of the fundus appears. As a

FIG. 203.—The abdominal part of the digestive tube, the common dorsal mesentery, and the ventral or splanchnic branches of the aorta. (After Toldt) (From Kollmann's *Entwicklungsgeschichte*.)



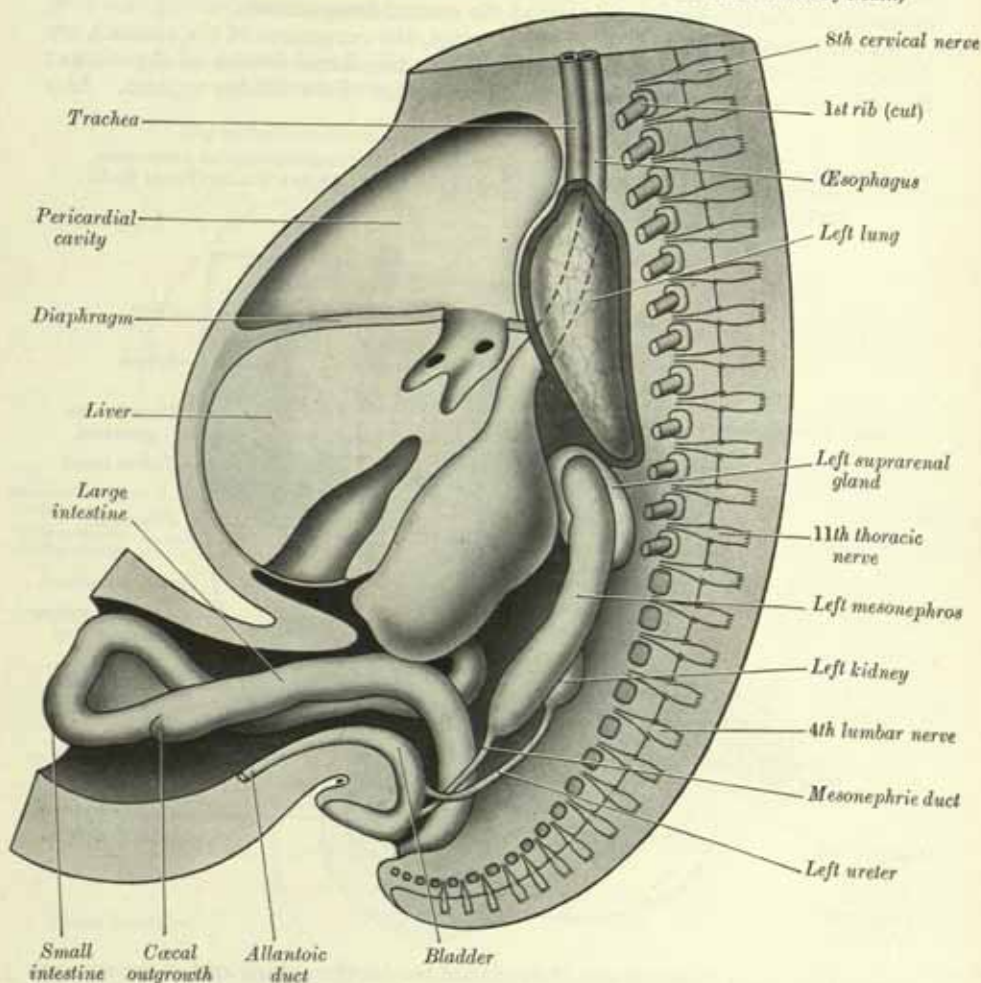
result of the more rapid growth of the dorsal border the pyloric end of the stomach is carried ventrally and the concavity of the lesser curvature becomes apparent (fig. 201). These growth changes in the stomach are associated with increasing depth of the dorsal mesogastrium, and all these factors, possibly together with pressure exerted by the rapidly growing liver, result in the displacement of the stomach to the left of the median plane and its rotation so that its right surface is directed dorsally and its left surface ventrally (fig. 211). As a result in the adult the right vagus nerve is distributed mainly to the posterior and the left vagus nerve mainly to the anterior surface of the stomach. In this way the recessus pancreatico-entericus, which was hitherto a simple recess in the dorsal mesogastrium (p. 196), comes to lie dorsal to the stomach and may now be termed the inferior recess of the bursa omentalis.

While these changes are occurring in the stomach, the gut increases in length more rapidly than the vertebral column, and forms a U-shaped loop, which acquires a dorsal mesentery as it lengthens, and projects into the coelomic cavity (fig. 203). The rapidly growing liver and the developing mesonephroi encroach on the avail-

able space in the cœlom so much that the U-loop is extruded into the portion of the extra-embryonic cœlom which becomes included in the umbilical cord (p. 88). *This umbilical hernia is a normal condition in human embryos between the 10 mm. (end of fifth week) and the 40 mm. stage (third month); under abnormal conditions it may be present at birth.*

The rotation of the stomach reacts on the position of the duodenum, which prior to this stage forms a ventrally directed loop, now carried dorsally and to the right. At this stage the duodenum possesses a thick mesentery, which is continuous with

FIG. 204.—The trunk of a human embryo 17 mm. long. (After a reconstruction by Mall.)



Note.—Rotation of the U-loop of gut has brought the distal limb of the loop to the left side. The whole loop lies in the proximal part of the umbilical cord, forming an umbilical hernia, which is normal at this stage. The upper pole of the left suprarenal gland lies in the left pleuro-peritoneal opening in contact with the basal part of the developing lung.

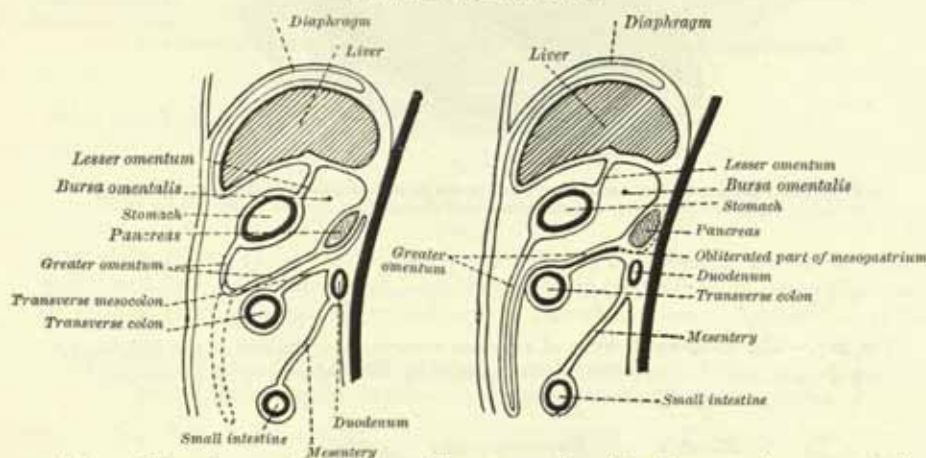
the dorsal mesogastrium, on the one hand, and the mesentery of the U-loop, on the other (fig. 203). At a later stage the approximation of the duodenum to the dorsal abdominal wall leads first to the adhesion of the right layer of its mesentery to the parietal peritoneum, and later to the absorption of both layers. In this way the duodenum comes to be retroperitoneal.

Early in the sixth week a small diverticulum appears on the caudal limb of the U-loop (fig. 201) and is later differentiated into the cæcum and the vermiform appendix. Thereafter it is possible to distinguish the large from the small intestine. Until the fifth month the diverticulum has a conical outline, but from that time onwards its distal part remains rudimentary and forms the vermiform appendix, while its proximal part expands to form the cæcum. At birth the vermiform appendix springs

from the apex of the cæcum, but, owing to unequal growth in the walls of the latter, it subsequently comes to open on the medial side of the cæcum.

When the U-loop enters the umbilical cord it has already been rotated through an angle of 90° , so that the proximal limb (i.e. the limb nearer to the stomach) lies to the right and the distal limb to the left (fig. 204). This relative position is maintained so long as the hernia persists, but during this period the portion which forms the small intestine becomes elongated and coiled, and the mesentery adapts itself to the changes in the gut. The colic part of the hernia elongates less rapidly and has no tendency to become coiled. By the time the embryo has attained a length of 40 mm. (middle of third month), the peritoneal cavity has enlarged sufficiently to contain all the abdominal viscera, and the hernia undergoes rapid reduction. The manner in which this occurs is important, for it is at this stage that the gut undergoes a process of *rotation*, resulting in the establishment of the very constant relationships which the large intestine shows in the adult, including the relation of the transverse colon to the duodenum. The process has been analysed by Frazer and Robbins * as follows. So long as the hernia is present, the dorsal mesentery forms a median partition extending from the dorsal wall to the umbilicus. As the gut re-enters the abdominal cavity the coils of the small intestine, which return first, necessarily enter to the right of this partition and they thrust it over to the left, thus determining the

FIG. 205.—Diagrams to illustrate the development of the greater omentum and the transverse mesocolon.



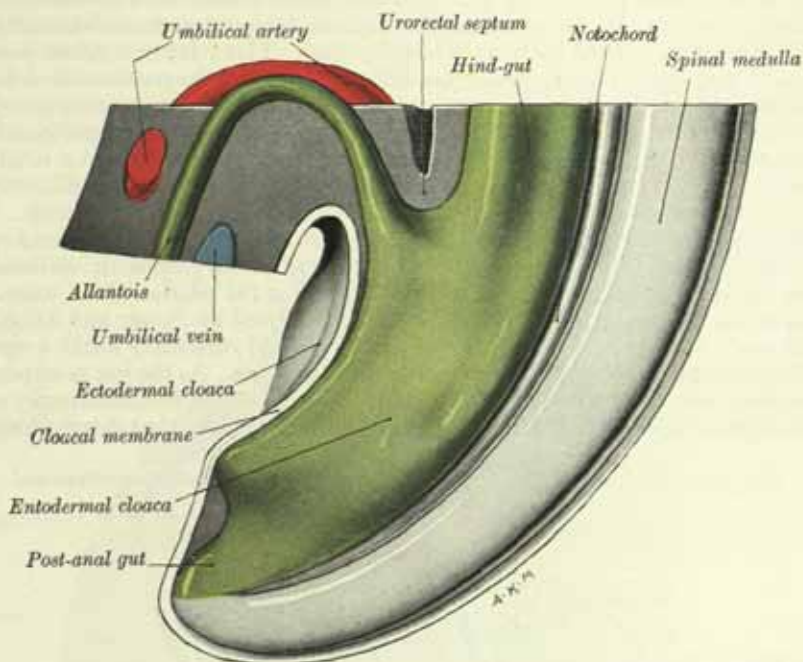
position of the descending colon. They pass dorsal to the superior mesenteric artery and determine its adult relationship to the inferior part of the duodenum. The cæcum is the last part to re-enter the abdomen, and it lies at first on the surface of the coils of the ileum. The subsequent growth changes soon carry the cæcum dorsally and to the right, where it lies in contact with the caudal aspect of the liver. The portion of the colon which adjoins the cæcum now lies ventral to the duodenum and the rotation of the gut has been completed.

As a result of the manner in which the coils of small intestine re-enter the abdominal cavity the mesentery of the descending colon is thrust against the dorsal abdominal wall and the opposed peritoneal surfaces become adherent and are gradually absorbed. In this way the descending colon loses its mesentery and becomes retroperitoneal. Since this change takes place towards the end of the third month the left colic vessels, whose position on the posterior abdominal wall is secondary, must lie in front of such structures as the left ureter and testicular or ovarian vessels, which are associated with the posterior wall originally. At the same time the proximal part of the colon is carried behind the omental bursa, and fusion takes place between the transverse mesocolon and the dorsal wall of the bursa (fig. 205), (see also p. 1402). During the later months of fetal life the cæcum descends into the right iliac fossa, and the ascending colon so formed loses its mesentery in the same way and with the same results as happened in the case of the descending colon.

The rectum and anal canal.—The formation of the tail-fold and the changes associated with it have been described in an earlier section (p. 81). As growth

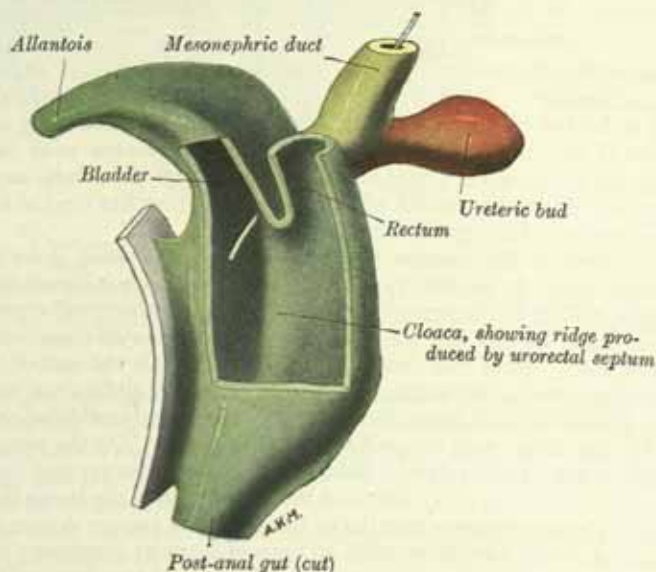
* J. E. Frazer and R. H. Robbins, *J. Anat. Lond.*, 50, 1916.

FIG. 206.—The tail-end of a human embryo, about four weeks old.
(Drawn from a model by Keibel.)



The model has been dissected to show the left lateral aspects of the spinal medulla, notochord and entodermal cloaca.

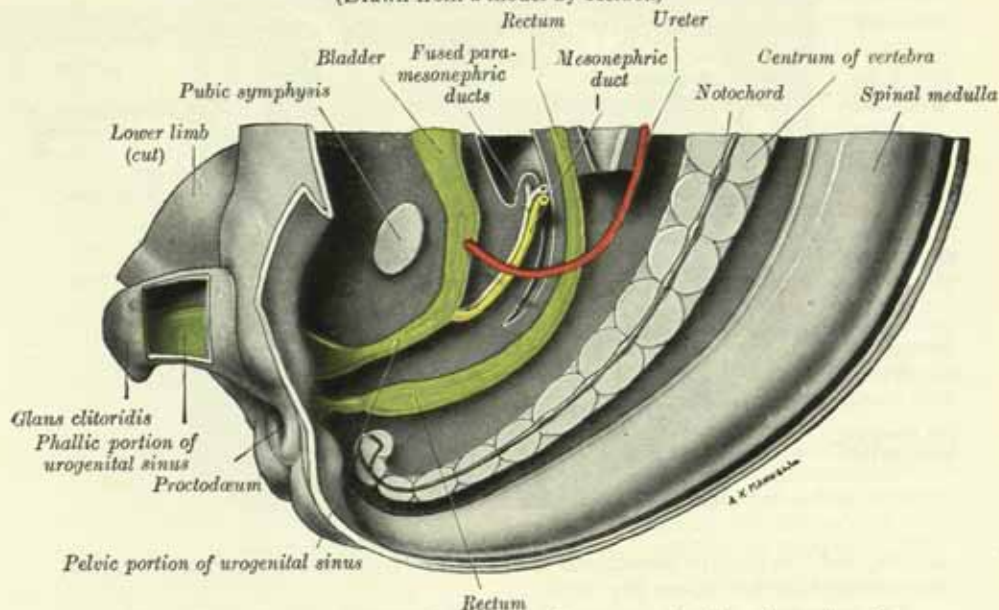
FIG. 207.—The entodermal cloaca of a human embryo, near the end of the fifth week.
(Drawn from a model by Keibel.)



Note.—A wire has been passed along the right mesonephric duct into the cloaca, and a part of the left wall of the cloaca, including the left mesonephric duct, has been removed, together with the adjoining portions of the walls of the developing bladder and rectum. A piece of the ectoderm around the cloacal membrane has been left *in situ* and is uncoloured.

proceeds, the gut lengthens, at first *pari passu* with the embryo, and a new portion of the hind-gut can be recognised between the caudal aspect of the vitelline duct and the origin of the allantois (fig. 202). The part of the hind-gut caudal to the

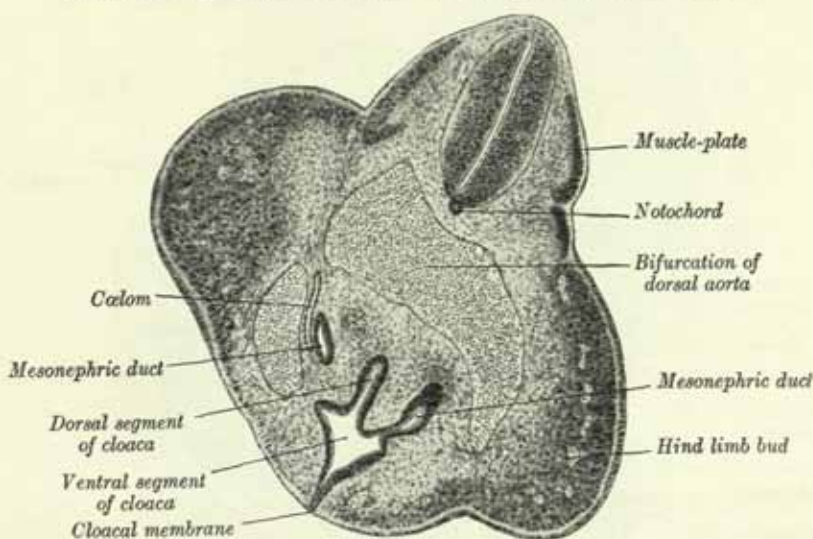
FIG. 208.—The tail-end of a female human embryo, eight and a half to nine weeks old. (Drawn from a model by Keibel.)



The model has been dissected from the left side to show the structures in and near the median plane. Note that the cloaca has now been separated completely into urogenital and intestinal segments.

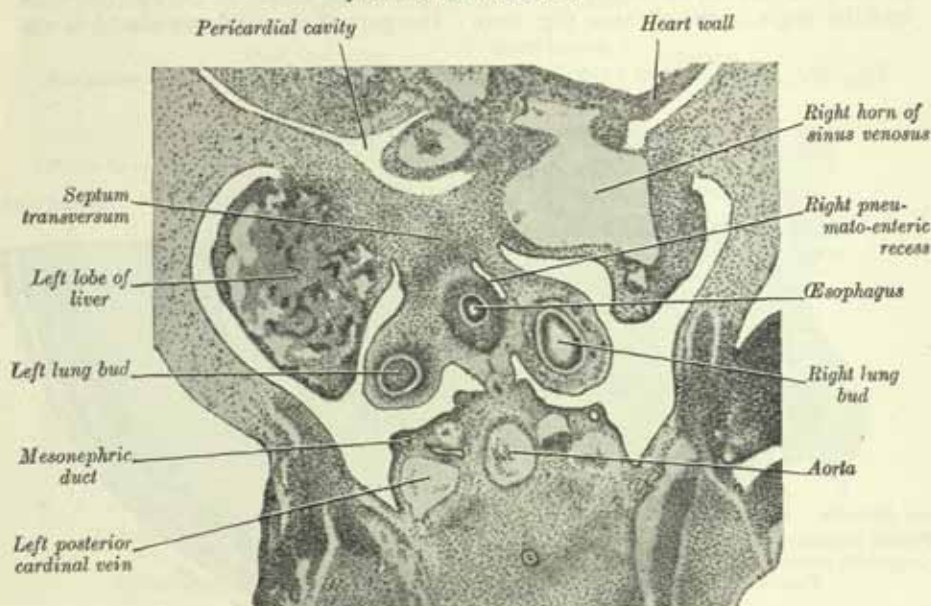
latter point dilates to form a pouch, termed the *entodermal cloaca*, and in its ventral wall the cloacal membrane (p. 84) can be identified in the median plane (fig. 206). By growth of the surrounding mesoderm the cloacal membrane comes to lie at the

FIG. 209.—Oblique transverse section through a mole embryo, 5 mm. long, at the level of the bifurcation of the aorta. (Drawn from a photomicrograph.)



bottom of a shallow depression termed the *ectodermal cloaca* (fig. 206). The hind-gut and the allantois open into the entodermal cloaca from the time of its first appearance and in the fifth week the mesonephric ducts pierce its wall. By this time the ventral part of the cloaca is wider than its dorsal part, which remains very

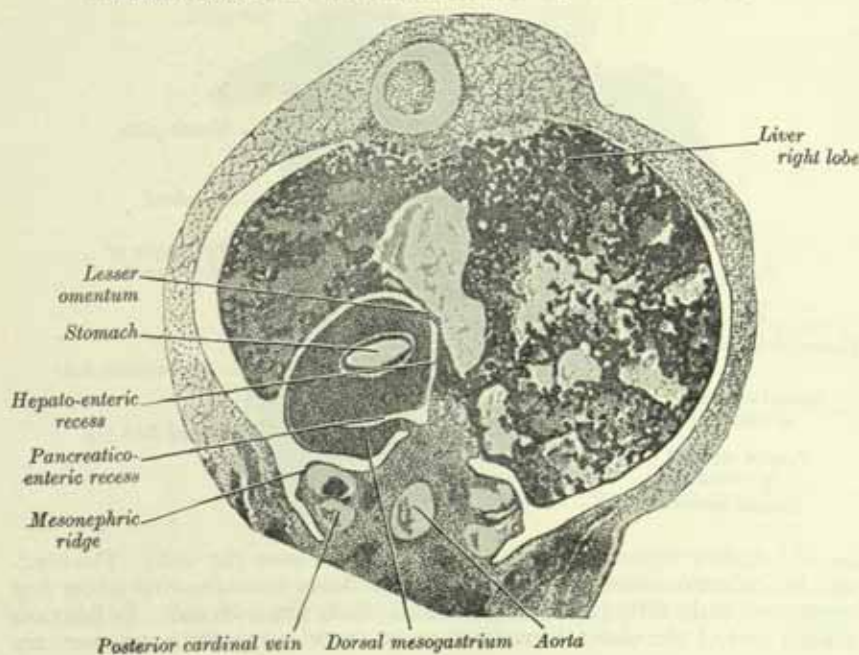
FIG. 210.—Transverse section of a human embryo 8 mm. long, showing the right pneumato-enteric recess.



narrow, and it is into the dorsilateral corner (lateral horn) of the ventral portion that the mesonephric duct opens (fig. 209).

The mesoderm outside the line of union of these two parts of the cloaca grows rapidly and thrusts the entodermal epithelium inwards. As a result the two walls come into apposition and fuse. This process commences opposite the connexion of the allantoic canal with the cloaca and is continued caudally to form a septum, termed the *urorectal septum*, which separates the dorsal segment or rectum from the ventral segment, which forms the urinary bladder and the urogenital sinus. At its

FIG. 211.—Transverse section through the same embryo as fig. 210, but 530 μ more caudally. Note that rotation of the stomach has taken place and that the sinusoidal spaces in the liver communicate freely with one another.



caudal end the urorectal septum reaches the cloacal membrane and divides it into an *anal* and a *urogenital membrane*. For a time a communication, named the *cloaca-duct*, exists between the two parts of the cloaca caudal to the growing urorectal septum (fig. 237); this duct occasionally persists as a passage between the rectum and the bladder or urethra. Anal tubercles * form round the margin of the anal part of the cloacal membrane, which thus comes to lie at the bottom of a depression, termed the *proctodæum*. On the absorption and disappearance of the anal membrane the rectum communicates with the exterior (fig. 208). The lower part of the anal canal is formed from the proctodæum, but its upper part is entodermal in origin and is derived from the caudal end of the dorsal subdivision of the cloaca; the line of union corresponds with the edges of the anal valves in the adult. In the fourth and fifth weeks a small part of the hind-gut, named the *post-anal gut* (fig. 206), projects tailwards beyond the anal membrane; it usually becomes obliterated and disappears before the end of the fifth week.†

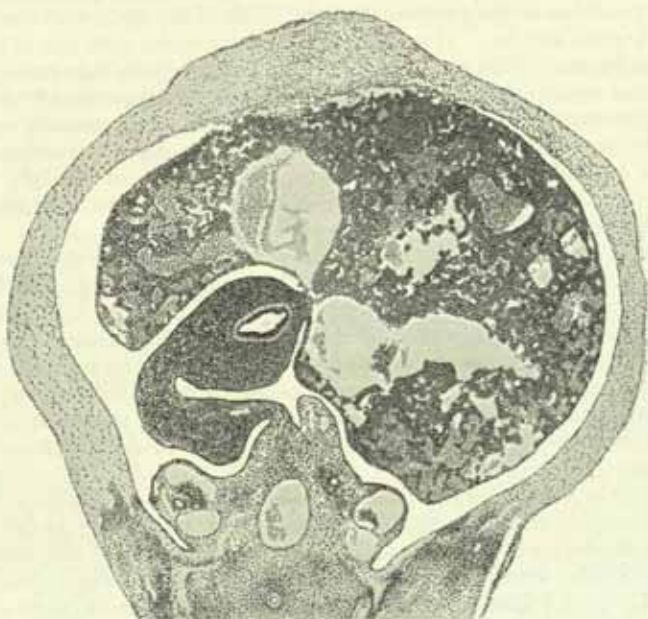
Applied Anatomy.—Abnormalities in the development of the digestive tube may lead to various disturbances which become apparent at birth or shortly after. Of these the following are the most common:

The closure of the laryngo-tracheal groove (p. 200) may be effected in such a way that the œsophagus is divided into two portions, viz. an upper, which communicates with the mouth above and ends blindly below in the neighbourhood of the tracheal bifurcation, and a lower, which communicates below with the stomach and above with the trachea.

Congenital stricture of the small intestine is usually due to exuberant overgrowth of the lining epithelium and the formation of adhesions. This overgrowth is a normal occurrence at one stage in the development of the duodenum, but the lumen is soon restored.

The umbilical hernia which is found between the 10 mm. and the 40 mm. stage may fail to return within the abdominal cavity (p. 191) and may be present at birth.

FIG. 212.—Transverse section through the same embryo as fig. 211, but 150μ more caudally. Compare with the preceding figure and observe that the 'bursa omentalis' communicates with the general peritoneal cavity at this level.



The vitello-intestinal duct (p. 188) may remain patent as a constituent of the umbilical cord or its proximal part may persist as a 'Meckel's diverticulum,' which may or may not be anchored to the umbilicus by a fibrous band. In its simplest form a

* E. M. Tench, *Am. J. Anat.*, 59, 1936.

† Consult in this connexion: "A Contribution to the Morphology of the Human Urogenital Tract," by D. Berry Hart, *Journal of Anatomy and Physiology*, 35, 1901.

'Meckel's diverticulum' is a short, sac-like protrusion from the antimesenteric border of the ileum about three feet above the ileo-colic valve.

Rotation of the gut (p. 191) may fail to occur. In these cases the colon occupies the left, lower portion of the abdominal cavity and has no connexion with the greater omentum: the duodenum may be spirally coiled and the superior mesenteric vessels pass either behind it or to its left side.

The cæcum may retain its foetal form with an apical vermiform appendix. It may fail to descend and is then found in front of the right kidney in close relation to the visceral surface of the liver. Occasionally it lies in the transverse mesocolon.

The separation of the entodermal cloaca into ventral and dorsal portions may be incomplete. The rectum then opens into the bladder, urethra or vagina and the anus is imperforate. The condition of imperforate anus may occur without other abnormalities. In some cases it is due to persistence of the anal membrane; in others, the colon may end blindly, considerably above the level of the pelvic floor. The proctodæum may or may not be present.

On account of its mode of development the anal canal is lined in its lower part by modified skin, and in its upper part by mucous membrane, which is entodermal in origin. Abrasions or tears of the wall of the lower part of the anal canal, such as occur in the condition known as anal fissure, are exceedingly sensitive and their examination causes acute pain. On the other hand, lesions of the upper part of the anal canal are never associated with pain, either subjective or objective.

The peritoneum and the omental bursa.—Before the stomach becomes rotated, two peritoneal pockets, termed the *right* and *left pneumato-enteric recesses*, appear on either side in the dorsal mesogastrium. The left pneumato-enteric recess is transitory and soon disappears leaving no trace. The right recess communicates with the peritoneal cavity by a small mouth opening to the right and extends cranially along the right side of the oesophagus towards the root of the right lung bud. The right wall of the recess is formed by a mesenteric fold termed the *caval fold*. Just below the right pneumato-enteric recess, and sharing with it a common aperture of communication with the peritoneal cavity, is a second recess which extends to the left in the dorsal mesogastrium. This is the *pancreatico-enteric recess* (formerly called the *bursa omentalis*). Its mouth extends from the oesophageal end of the stomach to the duodenum; the cranial and caudal margins of this opening occupy the positions of the gastro-pancreatic folds of the adult and contain the left gastric and hepatic arteries. The pancreatico-enteric recess does not, at first, involve the mesoduodenum. The rotation of the stomach deepens this recess which lies dorsal to it and which extends to the left in the dorsal mesogastrium.* At the caudal end of the pneumato-enteric recess a further peritoneal recess extends ventrally and separates the stomach and liver. This is termed the *hepato-enteric recess*. This comes to lie behind the ventral mesogastrium and is carried caudally behind the mesoduodenum. When the caudate lobe of the liver develops it invades the caval fold and then projects from it into the hepato-enteric recess.

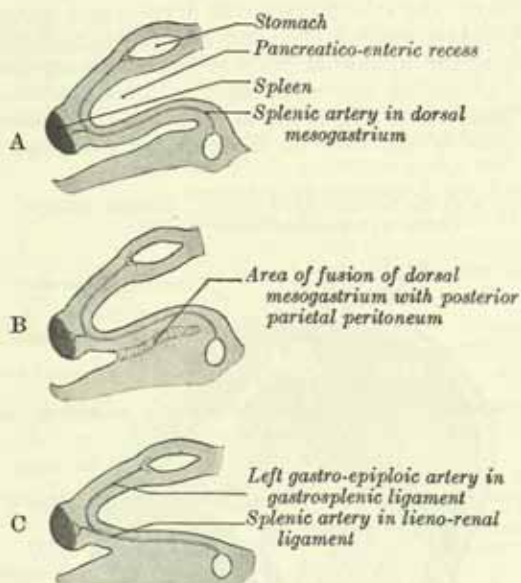
The cranial part of the pneumato-enteric recess is cut off by the development of the diaphragm and forms a small serous sac, the *bursa infracardiaca*, within the right pulmonary ligament between the oesophagus and diaphragm. The remainder of this complicated system of peritoneal recesses together constitutes the adult *bursa omentalis* and the common communication with the peritoneal cavity is the *foramen epiploicum*. The caudal part of the pneumato-enteric recess with the hepato-enteric recess form the superior recess of the bursa omentalis in the adult and the pancreatico-enteric recess gives rise to the inferior recess of the bursa omentalis and its extensions.

As the stomach enlarges the pancreatico-enteric recess keeps pace with it, and when the intestines return to the abdominal cavity they come to lie caudal and dorsal to its caudal part. In its cephalic part the dorsal wall of the recess becomes pressed against the dorsal abdominal wall and the opposed peritoneal layers fuse (fig. 213). Up to this time the dorsal mesogastrium is attached in the median plane, but as the result of the fusion the root of the mesogastrium acquires a new, curved attachment of the dorsal wall. From the oesophagus it passes tailwards and to the left, giving the gastrophrenic and lienorenal ligaments of the adult, and then turns to the right and grows somewhat caudally and to the right along the line of the pancreas (fig. 205).

* In Frazer's opinion the expansion of the pancreatico-enteric recess is the active factor in determining the rotation of the stomach and its displacement to the left.

The development of the spleen in the cephalic part of the dorsal mesogastrium (p. 199) subdivides that part of it into a lienorenal and a gastrosplenic ligament. The

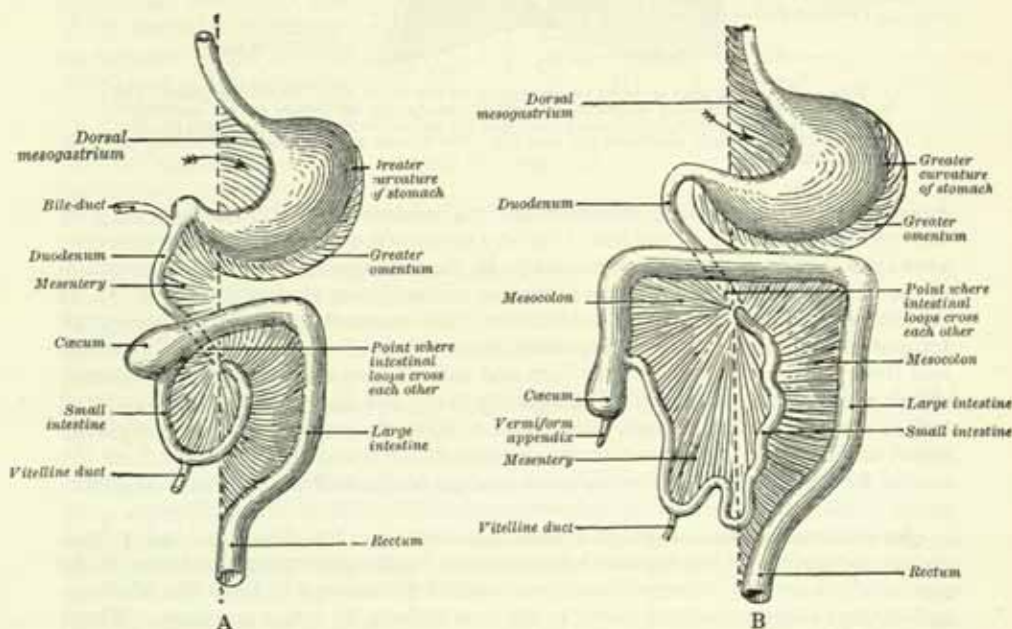
FIG. 213.—Diagram to show the fusion of the proximal part of the dorsal mesogastrium with the peritoneum on the posterior abdominal wall. Note also the conversion of the dorsal mesogastrium into the gastro-splenic and lienorenal ligaments.



A, represents a transverse section of an embryo in which the dorsal mesogastrium is still at the stage shown in fig. 211.

B and C, represent transverse sections of older embryos made at the same level.

FIG. 214.—Diagrams to illustrate two stages in the development of the digestive tube and its mesentery. The arrow indicates the entrance to the bursa omentalis.

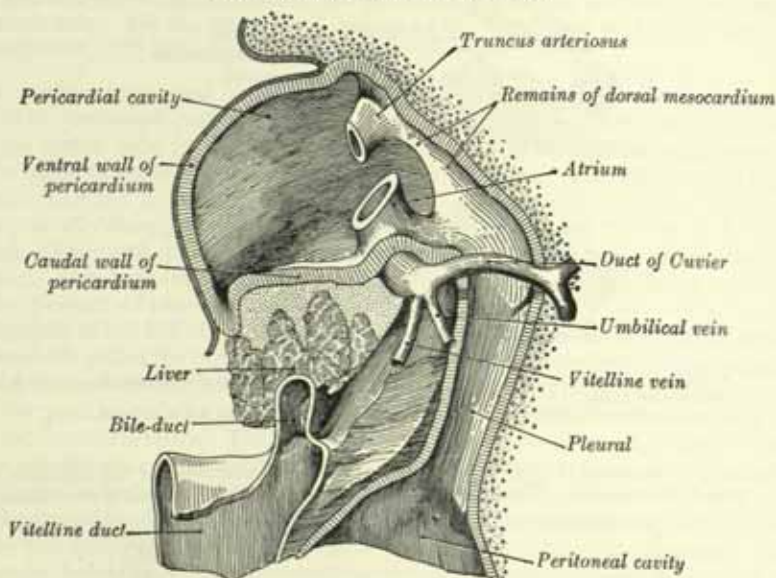


caudal part of the dorsal wall of the recess remains free and grows caudally overlapping the transverse colon and the underlying coils of small intestine, forming the

greater omentum. Later the two layers of the transverse mesocolon become adherent to the overhanging dorsal surface of the greater omentum, so that the adult condition is attained (fig. 205).

The liver arises in the fourth week as a diverticulum from the ventral surface of the fore-gut close to the point where the latter joins the vitelline duct (figs. 202 and 215). This diverticulum is lined with entoderm, and grows ventrally and headwards into the septum transversum, giving off two solid buds of cells, which represent the right and the left lobes of the liver. The solid buds of cells develop into epithelial trabeculae, termed the *hepatic cylinders*, which branch and anastomose to form a close meshwork. The intervals of the meshwork become filled with capillary-like vessels, termed *sinusoids*, and on section the organ takes on the appearance of a vascular sponge (fig. 212). These vessels arise *in situ* as the result of the influence exercised by the entodermal cells of the liver on the potentially angiogenic cells of the

FIG. 215.—The liver with the septum transversum. Human embryo, 3 mm. long. (After a model and figure by His.)



Note.—The pericardium is shown on parasagittal section to the left of the median plane. The section has also laid open the left pleuro-pericardial opening, the left pleural coelom and the left pleuro-peritoneal opening. In addition a portion of the wall of the vitello-intestinal duct has been removed and the hepatic outgrowth has been cut. The hepatic cylinders are seen invading the septum transversum.

mesenchyme of the septum transversum.* The invasion of the vitelline veins by the epithelial trabeculae of the liver to form a sinusoidal system of vessels occurs only over a restricted area in a few mammals.† By the continued growth and ramification of the entodermal hepatic cylinders the mass of the liver is gradually formed, but its connective tissue stroma is derived from included mesenchymal cells of the septum transversum. The original diverticulum from the duodenum forms the bile duct, and from its distal part the cystic duct and gall bladder arise as a solid outgrowth which later acquires a lumen. The opening of the bile duct is at first in the ventral wall of the duodenum; later, it migrates to the left across the dorsal (originally right) surface of the duodenum to the position which it occupies in the adult on the medial (or mesenteric) border. This migration of the orifice is effected by differences in the rates of growth in different parts of the walls of the duodenum.

As the liver enlarges, it projects more and more into the abdominal cavity from the caudal surface of the septum transversum. In the process mesenchyme of the septum transversum becomes drawn out ventral to the liver to form the falciform and coronary ligaments, and dorsal to the liver to form the lesser omentum. These peritoneal folds are sometimes termed the ventral mesogastrum. About the third

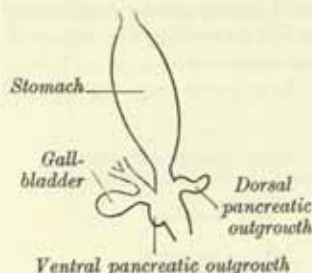
* G. L. Streeter, *Contr. Embryol. Carneg. Instn.*, 30, 1942.

† H. Elias, *Biol. Rev.*, 30, 1955.

month the liver almost fills the abdominal cavity, and its left lobe is nearly as large as its right. From this period the relative development of the liver is less active, more especially that of the left lobe, which actually undergoes some degeneration and becomes smaller than the right; but until birth the liver remains relatively larger than in the adult.

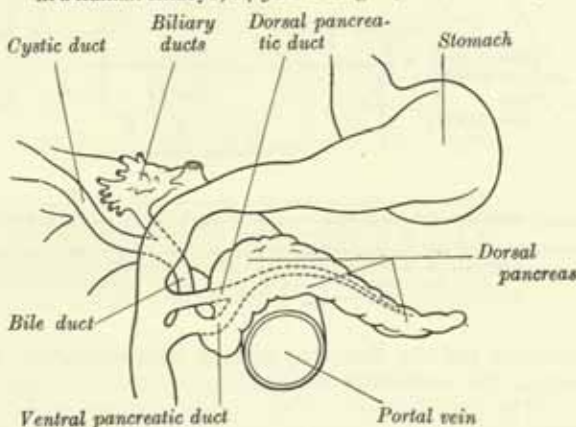
The pancreas (figs. 216 and 217).—The pancreas is developed in two parts, a dorsal and a ventral. The former arises in the latter half of the fourth week as a

FIG. 216.—Diagram of an early stage in the development of the pancreas in a human embryo, 7.5 mm. long. (After Streeter.)



diverticulum from the dorsal wall of the duodenum a short distance headwards of the hepatic diverticulum, and, growing headwards and dorsally in the mesoduodenum, enters that part of the dorsal mesogastrium which is forming the dorsal wall of the bursa omentalis. It forms the whole of the neck, body and tail of the pancreas and a part of the head. The ventral part appears in the form of a diverticulum from the primitive bile duct at the point where the latter opens into the duodenum. This diverticulum is at first double, but the two outgrowths soon fuse, and the diverticulum, now a single mass, grows round the gut into the mesoduodenum, where it enlarges to form the remainder of the head of the gland.* The duct of the dorsal part (accessory pancreatic duct) therefore opens directly into the duodenum, while that of the ventral part (pancreatic duct) opens with the bile duct. Early in the seventh week the two parts of the pancreas meet and fuse, and a communication is established between their ducts (fig. 217). After this has occurred the terminal part of the accessory duct, i.e. the part between the duodenum and the point of meeting of the two ducts, undergoes little or no enlargement, while the duct of the ventral part increases in size and forms the terminal part of the main duct of the gland. The opening of the accessory duct into the duodenum is sometimes obliterated, and, even when it remains patent, it is probable that the whole of the pancreatic secretion is conveyed through the main duct.

FIG. 217.—A later stage in the development of the pancreas in a human embryo, 14.5 mm. long. (After Streeter.)



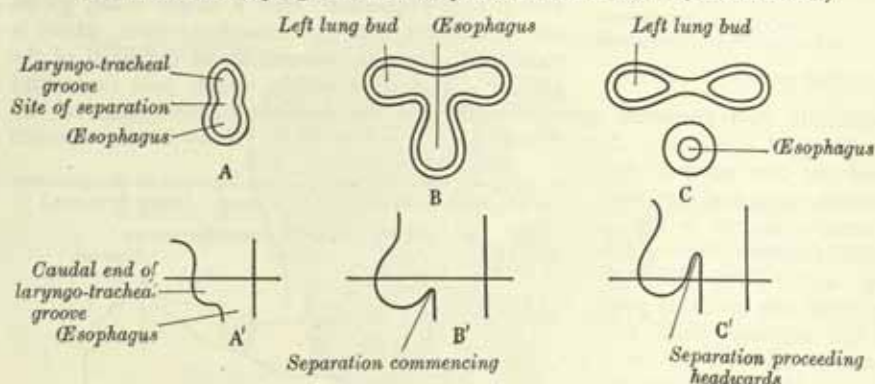
At first the body of the pancreas is directed headwards and dorsally between the two layers of the dorsal mesogastrium, in the dorsal wall of the bursa omentalis. When this wall fuses with the dorsal parietal peritoneum the process extends tailwards as far as the caudal (inferior) border of the pancreas, and thus, in the adult, the gland becomes retroperitoneal.

The spleen (figs. 213 and 203).—Although the spleen is not a constituent part of the digestive system, it is convenient to refer to its development here. It appears about the sixth week as a localised thickening of the coelomic epithelium of the dorsal mesogastrium in its cephalic portion, and the proliferating cells invade the underlying mesenchyme, which has become condensed and vascularised. The process occurs simultaneously in several adjoining areas which soon fuse to form a lobulated spleen, derived in part from the coelomic epithelium and in part from the mesenchyme in the dorsal mesogastrium. As the organ enlarges it projects to the left, so that its surfaces come to be covered with the peritoneum of the greater sac. When fusion occurs between the dorsal wall of the lesser sac and the dorsal parietal peritoneum, the process does not extend so far to the left as the spleen (fig. 213),

which remains connected to the dorsal abdominal wall by a short lienorenal ligament, while its primitive connexion with the stomach persists as the gastrosplenic ligament. The earlier lobulated character of the organ disappears but is indicated by the presence of notches on its upper border in the adult.

The respiratory organs.—The rudiment of the respiratory organs appears in the fourth week as a median *laryngo-tracheal groove* in the ventral wall of the pharynx. The groove deepens and its lips fuse to form a septum, which converts the groove into a tube, termed the *laryngo-tracheal tube* (fig. 218). The process of fusion commences at the caudal end of the groove and extends headwards, but it does not involve the cephalic end of the groove, where the lips remain separate, bounding a slitlike aperture, through which the tube opens into the pharynx. The tube is lined with entoderm, and from this the epithelial lining of the respiratory tract is developed. The cephalic part of the tube forms the larynx, and its succeeding part the trachea, while from its caudal end two lateral outgrowths arise and form the stem bronchi and the right and left *lung-buds*. These grow into the pleural

FIG. 218.—Diagrams to show the closure of the laryngo-tracheal groove and its separation from the œsophagus in the latter part of the fourth week. (After Streeter.)



A, B and C represent transverse sections at the levels shown in A', B' and C', which are outline drawings of the œsophageal region in three closely following stages.

In A and A' the laryngo-tracheal groove communicates freely with the œsophagus.

In B' the lower end of the laryngo-tracheal groove has begun to close and to form right and left evaginations, which represent the earliest rudiments of the lung buds, seen in B.

In C' the separation of the laryngo-tracheal groove from the œsophagus has proceeded further in a headward direction and in C the primitive lung buds are now freed from the œsophagus.

coeloms and are therefore covered with splanchnic mesenchyme (fig. 210), from which the connective tissue of the bronchi and lungs is developed.

The first rudiment of the larynx consists of the cephalic end of the laryngo-tracheal groove, bounded ventrally by the caudal part of the hypobranchial eminence (p. 183) and on each side by the ventral ends of the sixth arch (Frazer). Two arytenoid swellings appear, one on each side of the groove (fig. 197), and, as they enlarge, they become approximated to each other, and to the caudal part of the hypobranchial eminence (fig. 197), from which the epiglottis is developed. The upper aperture of the larynx is at first a vertical slit, which is converted into a T-shaped cleft by the enlargement of the arytenoid swellings; the vertical limb of the T lies between the two arytenoid swellings and its horizontal limb between them and the epiglottis. Soon after its appearance the epithelial walls of the cleft adhere to each other, and the aperture of the larynx remains occluded until the third month, when its lumen is regained. The upgrowth of the arytenoid swellings and the deepening of the primitive aryepiglottic folds form the walls of the vestibule and leave its aperture above the level of the primitive aperture, which now corresponds to the level of the glottis. The arytenoid swellings are differentiated into the arytenoid and corniculate cartilages, and the folds joining them to the epiglottis form the aryepiglottic folds, in which the cuneiform cartilages are developed as derivatives of the epiglottis. The thyroid cartilage is developed from the ventral ends of the cartilages of the fourth or fourth and fifth branchial arches; it appears as two lateral plates, each chondrified from two centres and united in the mid-ventral line by membrane in which an additional centre of chondrification

develops. The cricoid cartilage arises from two cartilaginous centres, which soon unite ventrally, and gradually extend and ultimately fuse on the dorsal surface of the tube (*see also* p. 118).

The right and left lung-buds make their appearance before the laryngo-tracheal groove is converted into a tube. They grow out into the pleural passages caudal to the ducts of Cuvier (fig. 215), and divide into lobules, three appearing on the right, and two on the left lung-bud; these subdivisions are the early indications of the corresponding lobes of the lungs (figs. 219 and 220). The buds undergo further subdivision and ramification, and ultimately end in minute expanded extremities—the infundibula of the lung. After the sixth month the air-sacs begin to make their appearance on the infundibula in the form of minute pouches. During the course of their development the lungs migrate in a caudal direction, so that by the time of birth the bifurcation of the trachea is opposite the fourth thoracic vertebra. As the

FIG. 219.—The lung-buds from a human embryo, 11·8 mm. long, showing commencing lobulation. (After Streeter, *Contr. Embryol. Carneg. Instn.*, 1948.)

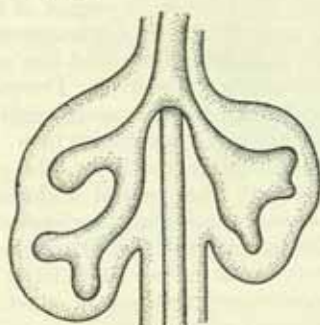
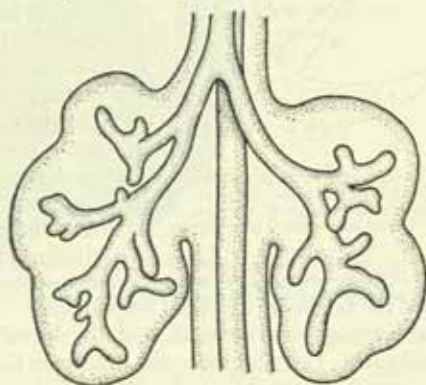


FIG. 220.—The lungs of a human embryo (14·2 mm. long) in the early part of the sixth week. (After Streeter, *Contr. Embryol. Carneg. Instn.*, 1948.)



lungs grow they project into the pleural passages (fig. 222) and the splanchnic mesoderm enveloping the lung rudiment expands on the growing lung and is converted into the pulmonary pleura.

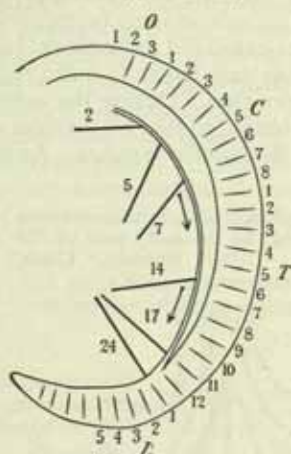
THE DEVELOPMENT OF THE BODY-CAVITIES

The formation of the intra-embryonic cœlom and the manner in which it communicates with the extra-embryonic cœlom have already been described (p. 79). After the formation of the head fold the pericardium communicates dorsally with the coelomic ducts which open caudally into the peritoneal cavity. When the lung buds develop they project into the coelomic ducts which may now be termed the *pleural* coeloms and their communications with the pericardial and peritoneal coeloms become the *pleuropericardial* and *pleuroperitoneal canals* respectively (fig. 215).

A ridge of tissue, termed the *pulmonary ridge*, develops on the lateral side of the pleural coelom and partly encircles the pleuropericardial canal. The ridge is continuous dorsally with the septum transversum. The developing lung bud abuts on the ridge which gives rise to two diverging membranes meeting at the septum transversum. One of these is cranially placed and is termed the *pleuropericardial membrane*; within its substance is the duct of Cuvier and the phrenic nerve which reach the septum transversum by this route. The other membrane is caudally placed and is termed the *pleuroperitoneal membrane*. As the apical part of the lung forms it invades the body-wall and extends cranially on the *lateral aspect* of the duct of Cuvier, carrying with it an extrusion of the pleural passage to form the definitive pleural sac. In this way the duct of Cuvier and the phrenic nerve come to lie medially in the mediastinum. The pleuropericardial canal, which lies medial to the vessel

is gradually narrowed to a slit which is soon obliterated by the apposition and fusion of its margins (fig. 222). Its closure occurs early and is mainly effected by the growth and expansion of the surrounding viscera, the heart, lungs, trachea and oesophagus and not by active growth of the pleuropericardial membrane across the opening to the root of the lung (fig. 222).

FIG. 221.—Schema showing stages in the descent of the septum transversum, (after Mall).



The numerals on the heavy lines indicate the length of the embryo in mm., and the position of the occipital, cervical, thoracic and lumbar segments is also shown.

wall. These attachments are the forerunners of the coronary and triangular ligaments and of the falciform ligament respectively. Medial to the pleuroperitoneal canals are the oesophagus and stomach with the dorsal mesentery and at the root of the latter the dorsal aorta. Dorsolateral to the canals are the pleuroperitoneal membranes, which remain small; dorsally are the Wolffian body, suprarenals and gonads. Just as the enlargement of the pleural cavity headwards and ventrally is effected by a process of burrowing into the body-wall, so its caudal enlargement is effected in the same way. The expanding pleural cavities extend into the mesoderm dorsal to the suprarenal glands, gonads and Wolffian body. This mesoderm is peeled off the dorsal body-wall to form a substantial portion of the lumbar part of the diaphragm. The pleuroperitoneal canal is closed by the fusion of its edges which are carried towards one another by the growth of the organs surrounding it and in particular of the suprarenal which carries the dorsal margin ventrally to meet the *pars diaphragmatica* of the septum transversum.* The right pleuroperitoneal canal closes earlier than the left. It is therefore on the left that an abnormal communication between the pleural and peritoneal cavities most frequently occurs. The further development of the peritoneal cavity has already been described (p. 196).

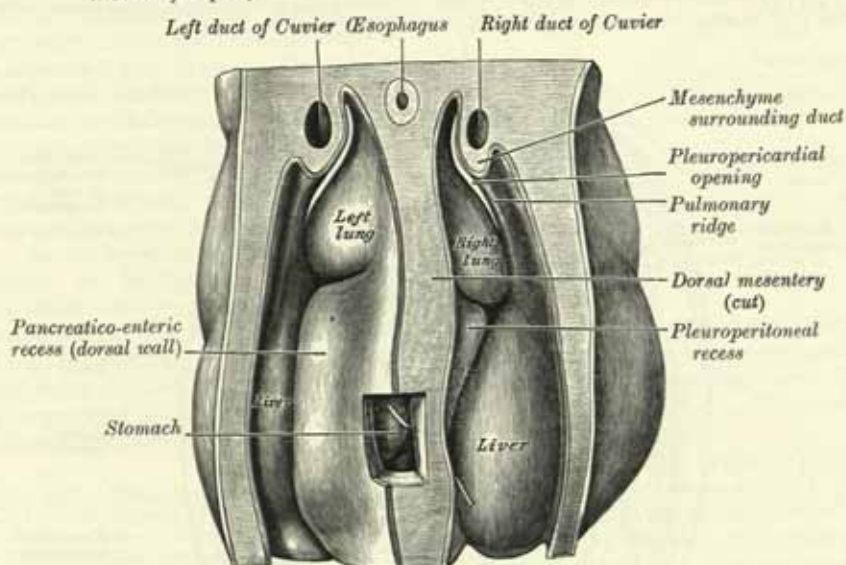
While these changes are in progress, the septum transversum undergoes a progressive alteration in position. In a human embryo, 2 mm. long, the dorsal border of the septum transversum lies opposite the second cervical segment, but as the embryo grows, and the heart enlarges, it migrates in a caudal direction. At first the ventral border moves more rapidly than the dorsal border, but after the embryo has attained a length of 5 mm. it is the dorsal border which migrates more rapidly (fig. 221). When the dorsal border of the septum transversum lies opposite the fourth cervical segment, the phrenic nerve (C 3, 4 and 5) and portions of the corresponding myotomes grow into it and accompany it in its later migrations. It is not until the end of the second month that the dorsal border of the septum transversum comes to lie opposite the last thoracic and first lumbar segments, the position which is occupied by its derivative, the diaphragm, in the adult.

The development of the diaphragm.—The closure of the pleuroperitoneal openings completes a mesodermal partition which separates the thoracic from the abdominal viscera and occupies the position of the diaphragm in the adult. This partition has a composite origin. The sternal and costal parts are derived almost exclusively from

* L. J. Wells, *Contr. Embryol. Carneg. Instn.*, 35, 1954.

the pars diaphragmatica of the septum transversum with a very small contribution dorsilaterally from the pleuroperitoneal membrane and from the chest wall (costal

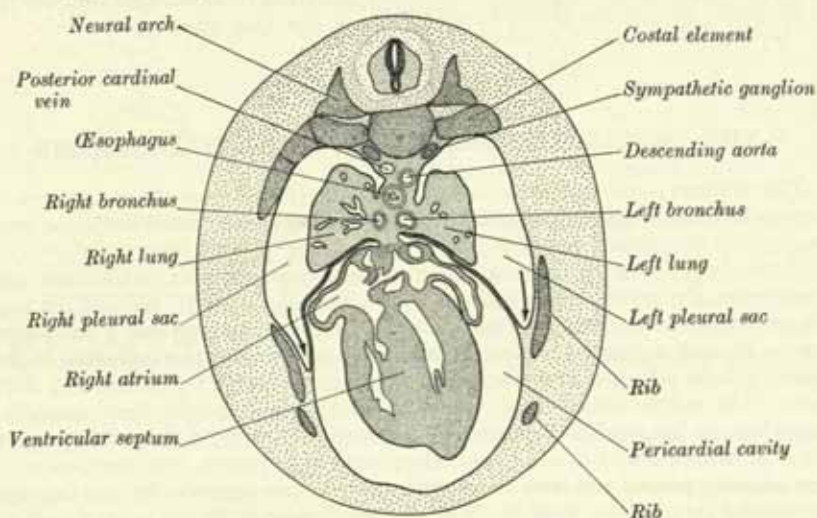
FIG. 222.—A view, from the dorsal aspect, into the thoraco-abdominal part of the coelom of a human embryo 6.8 mm. long. (Fifth week.) (From a model by Piper.)



Note.—The dorsal body-wall, including the spinal medulla, developing vertebral column, the dorsal aorta and the mesonephroi, has been removed. A window has been made in the dorsal wall of the pancreatico-enteric recess to expose the posterior surface of the stomach and a wire has been passed through the foramen epiploicum.

portion). In front of the oesophageal hiatus is a small contribution from the gastro-hepatic ligament which is derived from the pars mesenterica of the septum transversum. Between the oesophageal and aortic hiatuses it is formed in the dorsal

FIG. 223.—Transverse section of a 21 mm. human embryo, showing how the pleural sacs extend ventrally on each side of the pericardium. Semidiagrammatic.

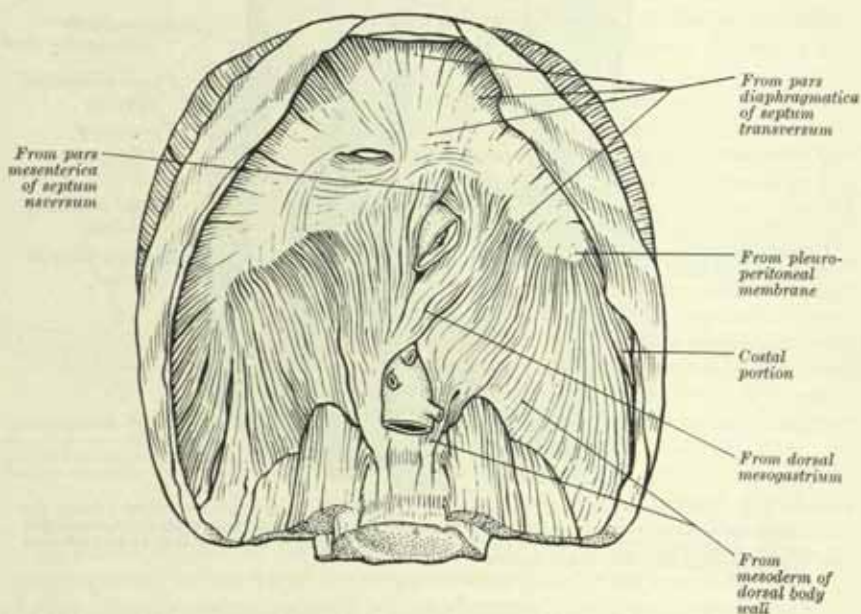


Note.—The arrows indicate the directions of growth of the two pleural sacs.

mesentery. The remainder of the lumbar part of the diaphragm is formed in the mesoderm around the abdominal aorta and more laterally in the mesoderm of the

dorsal body wall behind the suprarenal, Wolffian body and gonad.* Some authorities consider that much greater areas of the adult diaphragm are derived from the pleuroperitoneal membranes and from the chest wall.

FIG. 224.—Inferior surface of the diaphragm showing the derivation of the different parts. (After L. J. Wells, *Contr. Embryol., Carneg. Instn.*, 35, 1954.)



Gaps between the lumbar and costal portions of the diaphragm are due to under-development of the latter.

Premuscle tissue, derived principally from the fourth cervical myotome, invades the septum transversum as already described and from there extends into the rest of the partition, giving rise to the muscular diaphragm (fig. 224).

THE DEVELOPMENT OF THE UROGENITAL ORGANS

The excretory and reproductive organs are developed from the mesoderm of the intermediate cell mass (p. 77) and they are intimately associated with one another especially in the earlier stages of their development.

Typically, in lower vertebrates, the intermediate cell mass is divided into a series of segments, the *nephrotomes*, each of which develops a cavity, termed the *nephrocoele*, which communicates with the coelom through an opening called the *peritoneal funnel*. In each segment the dorsal wall of the nephrotome is evaginated to form a nephric tubule which communicates with the nephrocoele by means of a nephrostome. The outer ends of the earlier developed nephric tubules bend caudally and fuse to form a longitudinally running excretory duct, termed the *primary excretory duct*, which grows first caudally and then ventrally to open into the cloaca. The more caudally placed and later developed tubules open secondarily into this duct or into tubular outgrowths from it. The glomeruli arise from the ventral wall of the nephrocoele (internal glomeruli) or in the roof of the coelom adjacent to the peritoneal funnels (external glomeruli) or in both situations (fig. 225).

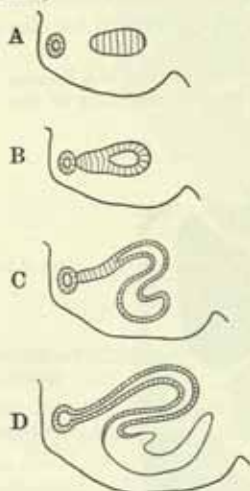
It has been customary to regard the excretory system as consisting of three

* L. J. Wells, *loc. cit.*

organs, the pronephros, mesonephros and metanephros, which succeed one another in time and space. The last of these to develop is retained as the permanent kidney. It must be noted however that it is impossible to provide reliable criteria that distinguish them as individual organs or to define their precise limits in the embryos of all animals. A pronephros cannot be distinguished as a separate organ in man. The earliest and most cranially situated nephric tubules are rudimentary and transient and are often regarded as marking the pronephric region. This region merges caudally without a clear line of demarcation into the mesonephros.

In the human embryo the development of nephrotomes and their cavitation to form nephrocoele which communicate with the coelom is confined to the levels of the most cranial somites. From about the level of the eighth somite caudally the mesoderm of the intermediate cell-mass is fused into an unsegmented column, termed the *nephrogenic cord*. This is connected at irregular intervals with the coelomic epithelium. No nephric tubules are developed at the most cranially-situated levels.

FIG. 226.—Diagram showing stages in the development of the nephric tubules and Malpighian corpuscles of the mesonephros. (After Felix.)

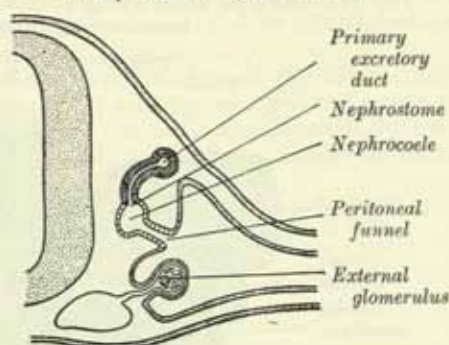


In A the tubule is a solid epithelial mass having no connexion with the primary excretory duct. In B and C it has acquired a lumen and is in contact with the duct. In D it has opened into the duct, while its opposite extremity has been invaginated by a vascular tuft (not shown in the diagram) and has been converted into a Malpighian corpuscle.

in association with these cranially-situated nephric tubules which are destined to disappear. It is doubtful whether external glomeruli develop in the human embryo.* The rudimentary nephric tubules constitute the pronephros of earlier workers.

Caudal to this is the mesonephros. It extends back to the level of the third lumbar segment and its nephric tubules are more completely differentiated and distinct internal glomeruli are formed. As in the more cranial region, each tubule first appears as a mass of cells which becomes hollowed in the centre. One end of

FIG. 225.—Diagram to show the derivatives of a nephrotome. (After Felix.)



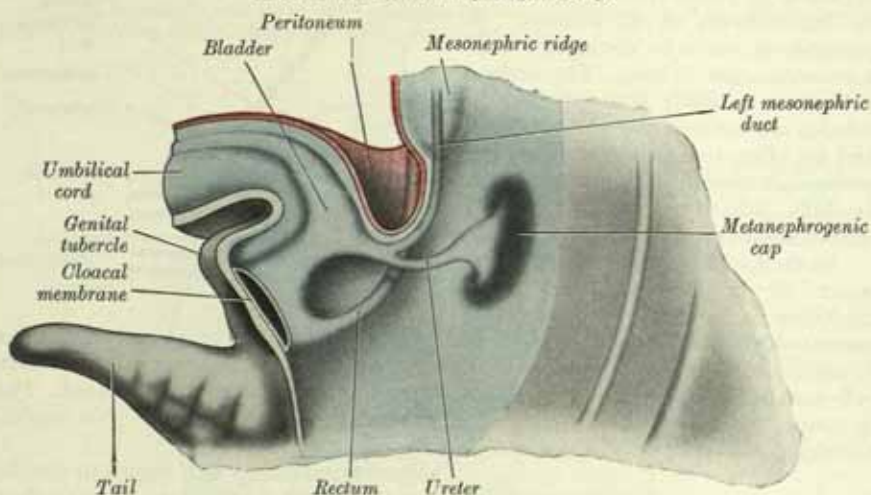
The *primary excretory duct* begins to develop in embryos of about 14 somites (23 to 24 days) as a solid cord of cells in the dorsal part of the nephrogenic cord. At this stage its cranial end is placed at about the level of the ninth somite and its caudal end merges with the undifferentiated mesoderm of the nephrogenic cord. It begins to differentiate before, and is at first not connected with, any nephric tubules. In older embryos it has lengthened and its caudal end has become detached from the nephrogenic cord to lie immediately beneath the ectoderm. From this level this rod of cells grows caudally, independently of the nephrogenic cord, and then curves ventrally to reach the wall of the cloaca. It becomes canalised progressively from its cranial end to form a duct which opens into the cloaca in embryos of 4 to 5 mm. length (about 28 days).

The mesonephros.—The *nephric tubules* are first indicated as clusters of cells in the nephrogenic cord. In regions cranial to the primary excretory duct these clusters develop no further. More caudally similar clusters of cells appear and become vesicular. The dorsal ends of these vesicles join the primary excretory duct, whilst their central ends are connected with the coelomic epithelium by cellular strands which probably represent rudimentary peritoneal funnels. Glomeruli are not developed

* T. W. Torrey, *Contr. Embryol. Carneg. Instn.*, 35, 1954.

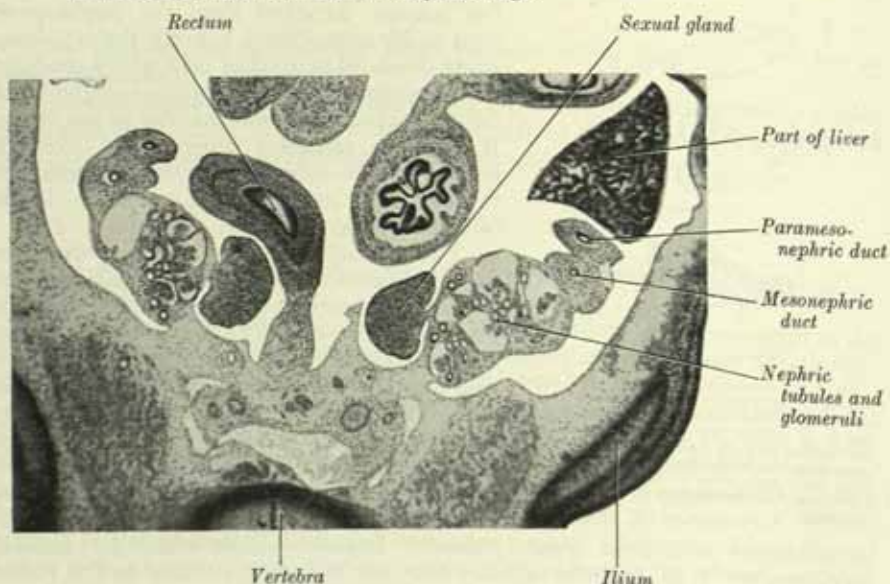
the vesicle grows towards and opens into the primary excretory duct which may now be termed the *mesonephric duct*, whilst the other end becomes dilated and is invaginated by a tuft of blood vessels supplied by a lateral branch of the aorta to form

FIG. 227.—Schema, based on fig. 237, to show the formation of the pelvis of the ureter and the metanephrogenic cap.



an internal glomerulus (fig. 226). In all, it is estimated that about 70 to 80 tubules and a corresponding number of glomeruli, which are not segmental in their arrangement, develop. All these tubules, however, are not present at the same time and it is rare to find more than 30 to 40 in any individual embryo, for the cranial tubules and

FIG. 228.—Transverse section through the lower part of the abdomen of a human embryo, 9 weeks old, showing the connexions and relative positions of the structures derived from the mesonephric ridge.

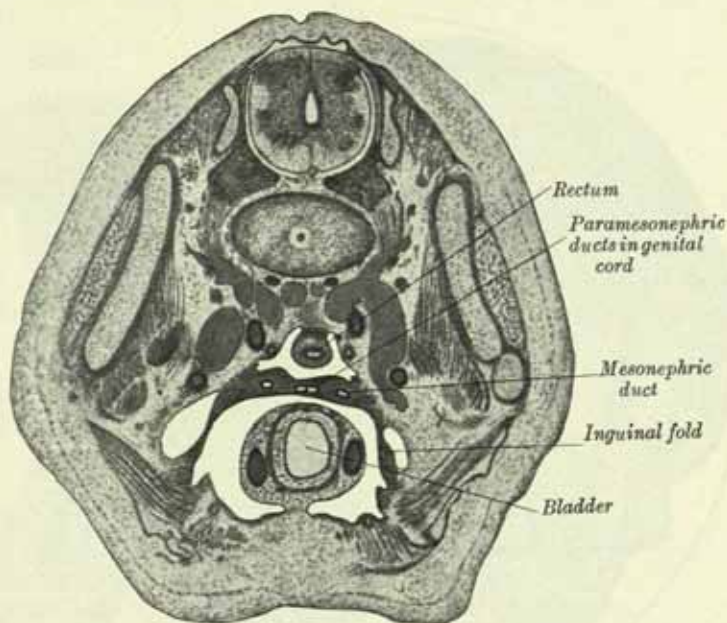


glomeruli atrophy and disappear before the development of those which are situated more caudally. By the end of the sixth week the mesonephros forms an elongated spindle-shaped organ which projects into the coelomic cavity on each side of the dorsal mesentery from the septum transversum to the third lumbar segment. This projection is termed the mesonephric ridge and the genital gland is developed on its medial surface.

In both sexes the cephalic end of the mesonephros atrophies and disappears, and in embryos of 20 mm. length the organ is found only in the first three lumbar segments, although it may still possess as many as twenty-six tubules.* Of these tubules the cephalic six to twelve persist to form the *effluent ducts of the testis* and the *lobules of the head of the epididymis*, in the male, and the tubules of the *epoöphoron*, in the female; the caudal tubules form the *ductus aberrans* and the *paradidymis*, in the male, and the *paroöphoron*, in the female.

The *mesonephric duct* runs tailwards in the lateral part of the mesonephric ridge, at the caudal end of which it is projected into the cavity of the coelom in the free border of a mesodermal fold (fig. 228). As the ducts approach the urogenital sinus the two folds fuse with each other, between the bladder ventrally,

FIG. 229.—Transverse section through the pelvic part of a human embryo, to show the formation of the genital cord and the inguinal folds. (From Quain's *Elements of Anatomy*, 11 edition, vol. i, "Embryology.")



and the rectum, dorsally, forming across the cavity of the pelvis a transverse partition which is termed the *genital cord* (fig. 229). In the male the peritoneal fossa between the bladder and the genital cord becomes obliterated, but it persists in the female as the uterovesical pouch. The mesonephric duct itself becomes the canal of the epididymis, the vas deferens and the ejaculatory duct in the male, and it later gives rise to a diverticulum which forms the seminal vesicle. In the female it constitutes the horizontal duct of the epoöphoron.

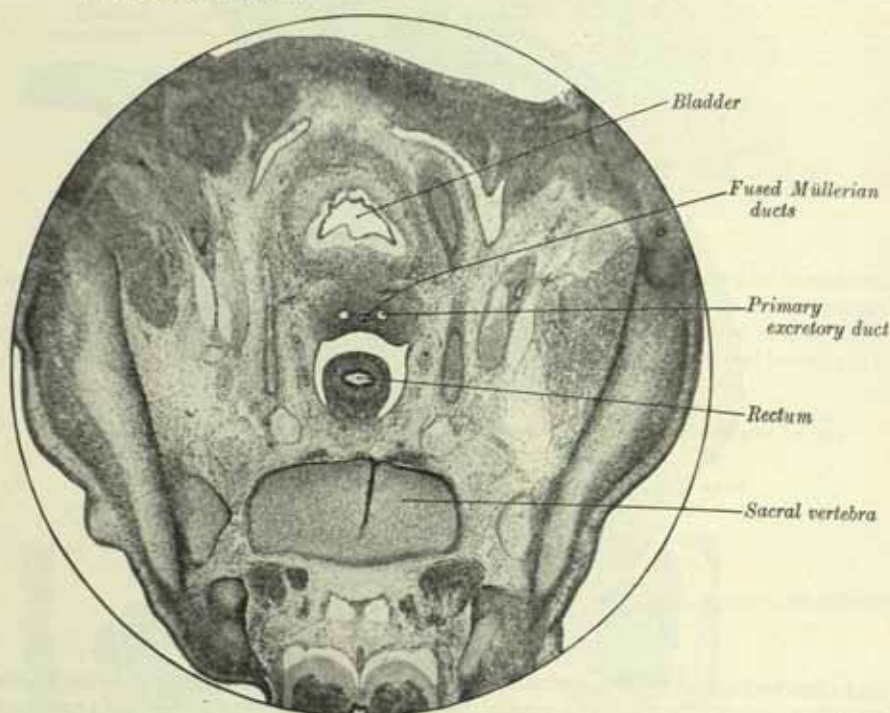
The **metanephros**, or permanent kidney, has a twofold origin. At about the 5 mm. stage an outgrowth forms from the dorsal and medial aspect of the mesonephric duct, near the point at which it opens into the cloaca. This outgrowth is the *ureteric diverticulum*, and it travels dorsally at first and then inclines headwards. Its blind extremity, which grows into the caudal end of the nephrogenic cord, becomes expanded and the adjoining mesoderm condenses around it to form the *metanephrogenic cap* (fig. 227). The presence of the actively-growing extremity of the ureteric diverticulum may be regarded as an important factor in determining the differentiation of the mesoderm, and it may be noted that in cases where the ureter fails to develop, no metanephrogenic cap is formed. The stalk of the ureteric diverticulum becomes the ureter, and its expanded end gives origin not only to the pelvis of the ureter and the calyces but also to the collecting tubules of the kidney.

* This massive degeneration of the more cranial tubules is described by Felix in Keibel and Mall's *Human Embryology*, but appears to have no parallel in other mammals.

The secreting and convoluted tubules and the renal corpuscles are all derived from the metanephrogenic cap. As a result, the blind ends of the secreting tubules must establish communication with the blind ends of the collecting tubules; should they fail to do so, congenital cysts of the kidney will be formed.

The expanded extremity of the ureter gives origin to four collecting tubules of the first order and itself forms the primitive renal pelvis. Each of these tubules ends in an ampullated extremity, which gives rise to collecting tubules of the second order. These, in turn, give rise to collecting tubules of the third order, and so on. In some animals the four collecting tubules of the first order are taken into the renal pelvis, which then presents a single renal papilla and no subdivision into calyces. In man, however, the collecting tubules of the first and second order persist and constitute, respectively, the major and minor calyces, while the tubules of the third

FIG. 230.—Transverse section through the pelvis of a nine weeks old human embryo, male, showing the approximation of the genital cord to the dorsal wall of the urogenital sinus.



and fourth orders are taken into the minor calyces which, therefore, directly receive the openings of the collecting tubules of the fifth order.

When it first appears the rudiment of the kidney lies in the pelvic region, but, as the ureteric outgrowth lengthens, it grows headwards and, by the time the embryo has attained a length of 13 mm., its expanded pelvis lies on a level with the second lumbar vertebra. During this period the developing kidney receives its blood-supply from arteries in its immediate neighbourhood, the middle sacral and common iliac arteries, but the definitive renal artery is not recognisable until the beginning of the third month. It arises from the most caudal of the three suprarenal arteries, all of which represent persistent mesonephric or lateral splanchnic arteries (p. 170). Additional renal arteries are by no means uncommon. They may enter at the hilum or at the upper or lower pole of the gland, and they also represent persistent mesonephric arteries.

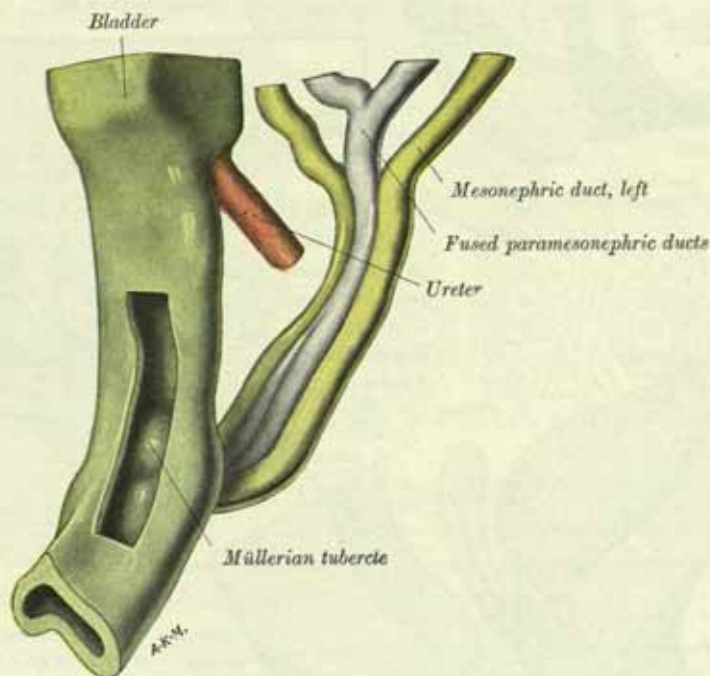
At an early stage the kidney is a lobulated organ, a condition which persists through foetal life but disappears during the first year after birth.

The ureter undergoes little alteration, save that it grows in length in conformity with the embryo. Two fusiform enlargements appear subsequently, one affecting its lumbar and the other its pelvic portion. The lumbar enlargement appears during

the fifth month, but the pelvic enlargement does not develop until the ninth month and is not constant. As a result the ureter shows a constriction at its upper end and another as it crosses the brim of the pelvis. A third constriction is always present at its lower end, and is caused by the growth of the bladder wall.

At first the ureter is connected to the dorsal and medial aspect of the mesonephric duct but, owing to differences in rates of growth, it comes to be connected to the lateral aspect of that structure. Thereafter the caudal end of the duct becomes incorporated in the developing bladder and the orifice of the ureter opens into the bladder on the lateral side of the opening of the duct. Later the two orifices become separated still further and, although the ureter retains its point of entry into the bladder, the mesonephric duct opens into that part of the urogenital sinus which subsequently becomes the prostatic urethra.

FIG. 231.—Part of the vesico-urethral portion of the entodermal cloaca of a female human embryo, eight and a half to nine weeks old. (Drawn from a model by Keibel.)

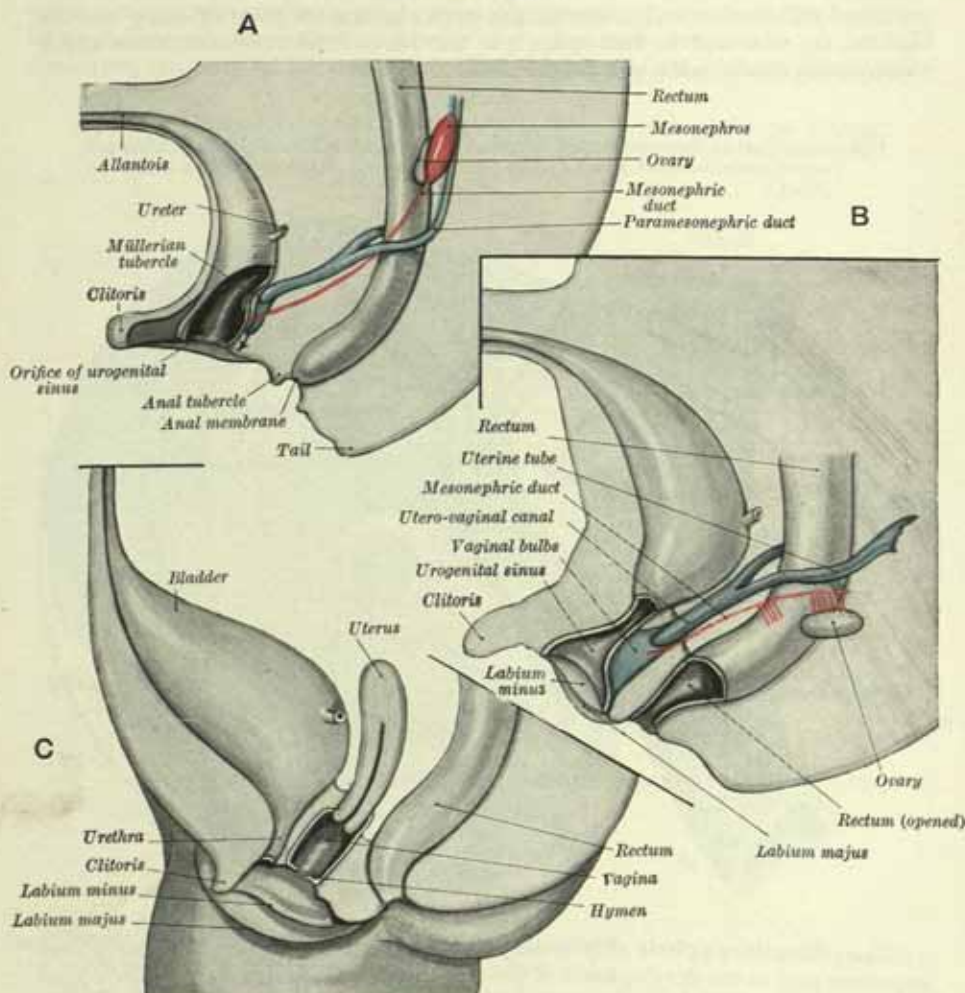


The **paramesonephric (Müllerian) ducts**, which are destined to play a very important part in the development of the reproductive system in the female, do not begin to develop until the embryo reaches a length of 10-12 mm. (beginning of sixth week). Each commences as a groove-like invagination of the coelomic epithelium on the lateral aspect of the mesonephric ridge near its cephalic end, and its blind end grows tailwards in the ridge as a solid rod of cells which acquires a lumen as it lengthens. Throughout the extent of the mesonephros it lies on the lateral side of the mesonephric duct. At the caudal end of the mesonephros, which it reaches in the eighth week, it bends medially (fig. 234, A) and crosses ventral to the mesonephric duct to enter the genital cord (figs. 229 and 230), where it bends caudally in close apposition with its fellow of the opposite side. The two ducts reach the dorsal wall of the urogenital sinus during the third month, and their blind ends produce an elevation on it termed the *Müllerian tubercle* or *eminence* (fig. 231). Each paramesonephric duct consists of an upper vertical, an intermediate horizontal, and a lower vertical portion. The upper vertical part forms the uterine tube, and the original coelomic invagination remains as the pelvic opening of the tube, the fimbriae becoming defined as the cephalic end of the mesonephros degenerates. The lower vertical parts of the two ducts fuse with each other to form the *uterovaginal canal*,

and as the uterine section enlarges it takes in the horizontal parts to form the fundus and most of the body of the adult uterus.

The caudal end of the uterovaginal canal becomes occluded by the proliferation of its lining epithelium, which gives rise to the formation of a central and two lateral vaginal bulbs.* These solid epithelial masses extend tailwards (fig. 232 A), increasing the size of the area of contact of the vagina with the urogenital sinus and

FIG. 232.—Diagram to show three stages in the development of the female generative organs.



The mesonephros, its duct and their derivatives are shown in red: the paramesonephric (Müllerian) ducts and their derivatives are shown in blue in A and B.

A. The left wall of the urogenital sinus has been removed to show the Müllerian tubercle on its dorsal wall: the vaginal bulbs which produce the tubercle are shown growing caudally in the direction of the arrow.

B. The mesonephros is represented by the tubules of the epoöphoron and paroöphoron. The vaginal bulbs have extended caudally along the dorsal wall of the urogenital sinus.

C. The condition at full term.

forming a conspicuous projection on the dorsal wall of the latter. The vagina grows much more rapidly than the surrounding parts and, owing to the way in which its caudal end enlarges and encroaches on the dorsal wall of the urogenital sinus, that structure becomes definitely shortened (fig. 232, B). The solid mass of cells destined to form the vagina later becomes canalised and the cavity so formed communicates at its cephalic end with the uterovaginal canal. A circular flange-like growth of

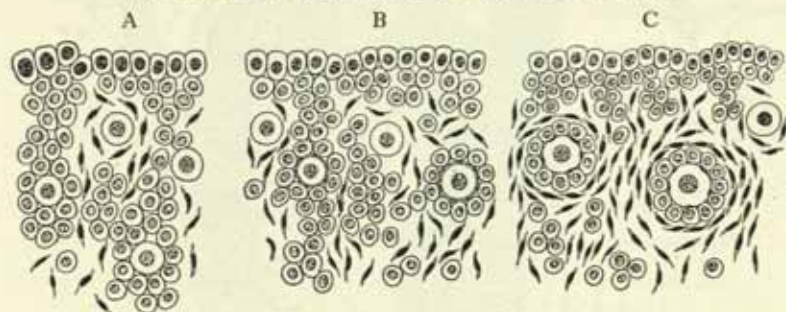
* J. Ernest Frazer and Alice Bloomfield, *J. Anat., Lond.*, **62**, 1928. See also A. K. Koff, *Contr. Embryol. Carnegie Instn.*, **24**, 1933.

epithelial cells occurs at the uterovaginal junction and its central cells later break down to form the fornices of the vagina. For a time the cavity of the vagina is separated from that of the urogenital sinus by a septum consisting of two layers; of these the inner is a layer of vaginal bulb tissue and the outer is a layer formed by the wall of the urogenital sinus. The septum subsequently breaks down in its central part to form the hymeneal orifice, while its peripheral part persists as the *hymen* (fig. 232, C). The caudal part of the urogenital sinus now receives two openings, viz. that of the urethra and that of the vagina (fig. 232, C). The part of the sinus caudal to these two openings forms the vestibule, which, after the rupture of the urogenital membrane, opens on the surface through a cleft bounded on each side by the genital fold (*labium minus*) (fig. 232, C).

The account given above is the one most generally accepted, but Zuckerman's work * on the effect produced on the vaginal epithelium in monkeys by the injection of endocrine secretions suggests that, in these animals, the urogenital sinus epithelium plays a much larger part in the formation of the lining of the vagina.

In the male the paramesonephric duct atrophies, but a vestige of its cephalic end persists as the *appendix testis*. The fused terminal portions of the two ducts (fig. 230) form the *prostatic utricle*, which opens into the floor of the prostatic part of the urethra.

FIG. 233.—Diagrams of early stages in the development of the ovary. The coelomic epithelium is shown as the covering layer in each figure.



A. End of second month. Four primitive sex cells are shown, recognisable by their large size and circular outline. Of these two are enclosed in sex cords and two others are lying free in the loose mesenchyme of the cortex.

B. Middle of fourth month. The primitive oögonia in the sex cords are encapsulated by the surrounding pregranulosa cells, which have become flattened.

C. End of fifth month. Stage of invasion by definitive stroma. Two oögonia are shown protected by their capsules of follicular cells, and, on the right, one of the unprotected oögonia is shown undergoing degenerative changes and its nucleus is becoming pyknotic.

The Germ Cells.—The precise origin of the *primordial germ cells*, or *primitive sex cells*, is still uncertain but comparative embryological evidence strongly suggests that they are derived either from the primitive entoderm (p. 70) or from a stem-cell common to them and to the primitive entodermal cells.†

In the human embryo they have been identified early in the fourth week (13 somite stage),‡ when they were present in the entoderm at the caudal end and adjoining roof of the yolk-sac. With the completion of the tail fold they are found in the entoderm and splanchnic mesoderm of the hindgut as well as in the neighbouring wall of the yolk-sac. Increasing in number by mitoses, they migrate actively by amoeboid movements in a dorsal and cranial direction in the dorsal mesentery and they pass laterally round the dorsal angle of the coelom to reach the medial aspect of the mesonephric ridge, which is the site of development of the gonad or genital gland.

The genital glands.—The first indication of the formation of the genital gland is the appearance of an area of thickened epithelium on the medial side of the mesonephric ridge in the fifth week. Elsewhere on the surface of the ridge the coelomic epithelium is one or two cells thick, but over the genital area it is many layered.

* S. Zuckerman, *Biol. Rev.*, **15**, 1940.

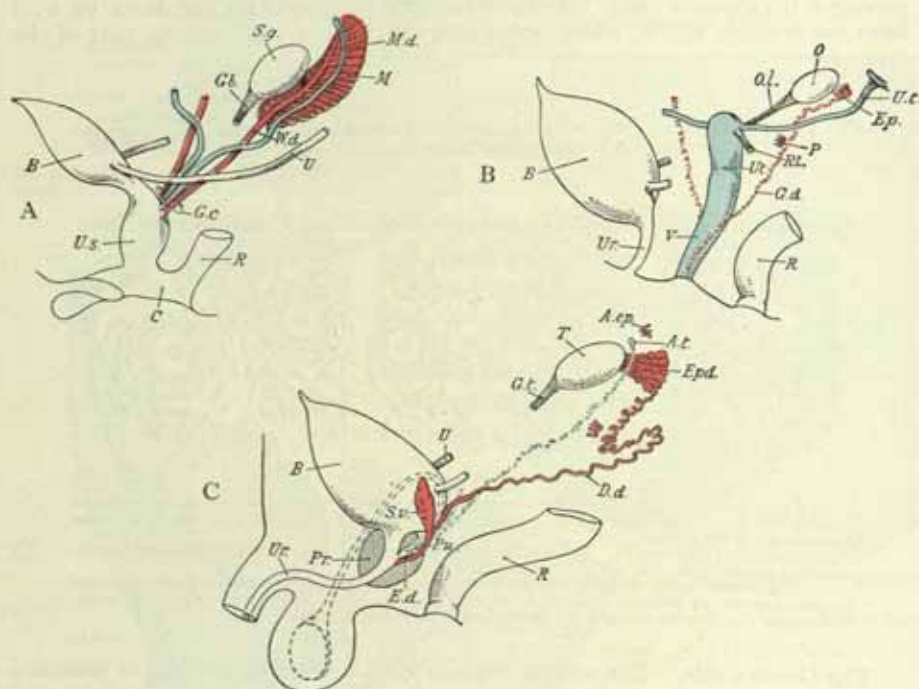
† M. L. Bounoure, *Ann. des sci. nat.*, **200**, **17**, 1934 and B. H. Willier, *Jour. Exper. Zool.*, **46**, 1937.

‡ E. Witschi, *Contr. Embryol. Carneg. Instn.*, **32**, 1948.

The thickening rapidly extends in a longitudinal direction until it covers nearly the whole of the medial surface of the ridge. The thickened epithelium continues to proliferate displacing the glomerular corpuscles of the mesonephros in a dorsolateral direction, and forming a projection into the coelomic cavity which is termed the *genital ridge*. Surface depressions form along the limits of the ridge, which is thus connected to the mesonephros by an originally broad *mesogenitale*. In this way the mesonephric ridge becomes subdivided into a lateral part containing the mesonephric and paramesonephric ducts, which may be termed the *tubal fold*, and

FIG. 134.—Diagrams to show the development of the male and female generative organs from a common type (after Allen Thomson). A. The condition in the embryo at the beginning of the third month. B. The female type of sexual organs. C. The male type of sexual organs.

The paramesonephric duct and its derivatives are shown in blue; the mesonephros, its duct and their derivatives are shown in red. The broken blue and red lines indicate that the structures shown normally disappear. The paradidymis is shown in III., but is not labelled.



A.ep. Appendix of epididymis. *A.t.* Appendix testis. *B.* Bladder. *C.* Cloaca. *D.d.* Ductus deferens. *Epd.* Epididymis. *E.d.* Ejaculatory duct. *Ep.* Epoöphoron. *G.c.* Genital cord. *G.d.* Duct of epoöphoron. *G.t.* Gubernaculum testis. *G.b.* Gubernaculum. *M.* Mesonephros. *M.d.* Paramesonephric duct. *O.* Ovary. *O.l.* Ovarian ligament. *P.* Paroöphoron. *Pr.* Prostate. *P.s.* Prostatic utricle. *R.* Rectum. *R.l.* Round ligament of uterus. *S.g.* Sexual gland. *S.e.* Seminal vesicle. *U.* Ureter. *Ur.* Urethra. *U.s.* Urogenital sinus. *U.* Uterus. *U.t.* Uterine tube. *V.* Vagina. *W.d.* Mesonephric duct.

a medial part, termed the *genital fold*. The tubal fold contains the nephric tubules and glomeruli at its base (fig. 228).

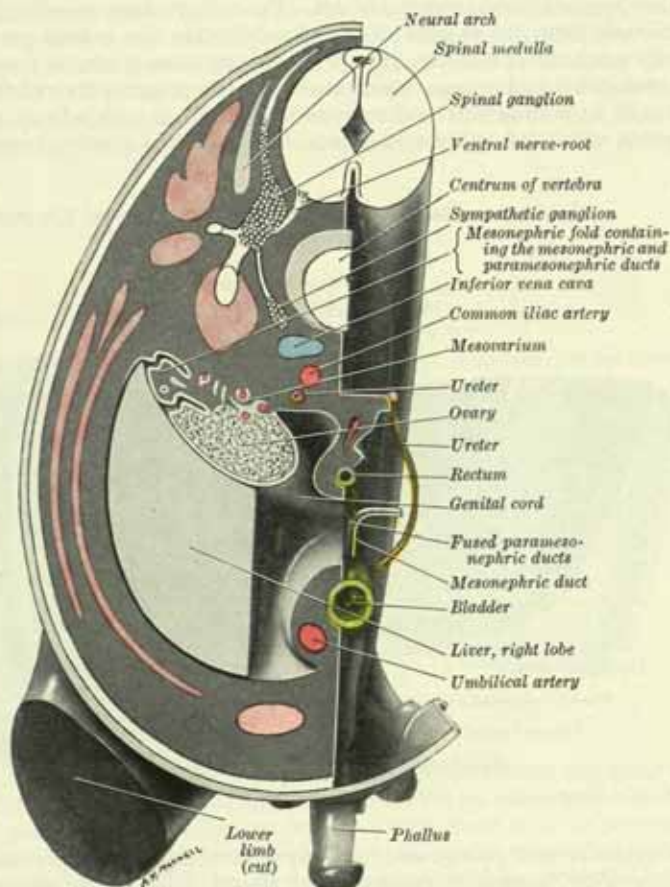
Up to the seventh week the genital gland possesses no differentiating features. The proliferating epithelium now forms a number of cellular cords, separated by mesenchyme. In the male all the progenitors of the definitive sex cells become incorporated in the cords, but in the female a large number remain behind under the surface epithelium. At this stage in the male, an extension of the mesenchyme cuts off the *testis cords* from the surface and rapidly thickens to form the *tunica albuginea*. In the female there is nothing comparable with the tunica albuginea and this offers a feature which serves to distinguish the testis from the ovary after the end of the second month.*

The testis.—The cellular cords lengthen, partly by additions from the coelomic

* For details see J. D. Boyd and W. J. Hamilton in K. Bowes, *Modern Trends in Obstetrics and Gynaecology*, London, 1955.

epithelium, and their inner ends converge towards the site of the hilum, where they unite in a network which ultimately becomes the *rete testis*. The outer parts of the testis cords become enlarged and form the seminiferous tubules. In the fourth (lunar) month the testis is invaded by a proliferation of the mesenchyme of the mesonephros. The incoming mesenchymal cells occupy the intervals between the sex cells and for a considerable period constitute more than one half of the volume of the organ.* In the later months of foetal life these cells undergo atrophy and

FIG. 235.—Part of the tail-end of a human embryo, eight and a half to nine weeks old. (Drawn from a model by Keibel.)



The left side of the drawing shows a transverse section through the right half of the trunk. The right side of the drawing shows a partial dissection of the left ureter, mesonephric, and paramesonephric ducts, etc.

degeneration, but small clusters of them persist to form the interstitial cells in the testis of the adult.

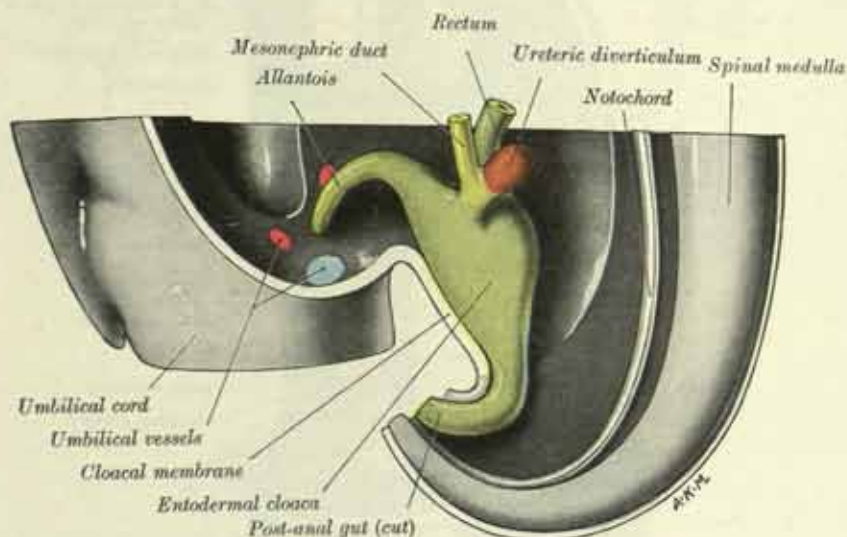
The cords of the rete testis become connected to the glomerular capsules* in the cephalic end of the persisting part of the mesonephros, and the glomerular tufts concerned become atrophied. The rete cords thus become connected to the mesonephric duct by the five to twelve most cephalic of the persisting tubules and these become exceedingly convoluted and form the lobules of the head of the epididymis. The mesonephric duct, which was the primitive ureter of the mesonephros, becomes the canal of the epididymis and the vas deferens of the testis. The seminiferous tubules do not acquire lumina until the seventh month, but the rete tubules do so at a somewhat earlier stage.

* J. Gillman, *Contr. Embryol. Carneg. Instrn.*, 32, 1948.

The ovary.—In its earliest stages the ovary closely resembles the testis, although it is slower to differentiate and to take on its characteristically female appearance. The sex cords of the indifferent stage extend through the gland to the region of the hilum, where they anastomose with one another to form a rete complex. As growth proceeds the cords lengthen and thicken, but at their cœlomic ends they form short, narrow stalks connecting with the cœlomic epithelium. In sections of the ovary in the third and subsequent months the cords have all the appearance of clusters of cells which may or may not contain primitive sex cells. These clusters are separated from one another by fine septa of undifferentiated mesenchyme.

In the fifth and sixth (lunar) months the ovary is the site of a secondary invasion by mesenchyme from the region of the mesovarium, where it surrounds the vessels as they approach and enter the hilum. From there these spindle-shaped cells, which ultimately form the stroma of the gland, invade the central part or medulla and finally reach the cortex (fig. 233 C). As this invasion proceeds the cell clusters break up into individual groups which surround the oögonia derived from the primitive sex cells, becoming flattened so as to provide them with cellular capsules.* Those oögonia which fail to become encapsulated undergo atretic changes and disappear.

FIG. 236.—The tail-end of a human embryo, about five weeks old.
(Drawn from a model by Keibel.)



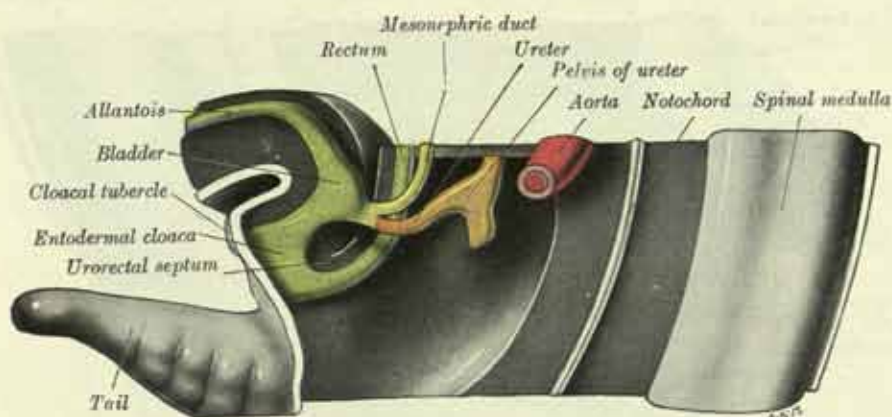
The capsular cells enlarge and multiply to form the stratum granulosum and, as they do so, they become surrounded by thecal cells which differentiate from the stroma (fig. 233 C). Many of the primordial follicles so formed become atretic and, according to the classic description, all the primordial follicles disappear entirely to be replaced by a second generation of sex cells derived from the cœlomic (germinal) epithelium. The opponents of the classic description believe that the later derivatives from the cœlomic epithelium are not oögonia but are destined to form capsules for unencapsulated oögonia, i.e. they are 'pre-granulosa' cells which subsequently form the strata granulosa for oögonia derived from the primitive sex cells but not yet atretic. According to this view the ova of the adult are all direct derivatives of the primordial germ cells.

The descent of the testis.—At first the testis lies on the dorsal abdominal wall, but, as it enlarges, its cephalic end degenerates, and the organ therefore assumes a more caudal position. The testis is attached to the mesonephric fold by a peritoneal fold, termed the *mesorchium* (fig. 228) (the mesogenitale of the undifferentiated genital gland), which contains the testicular vessels and nerves together with a quantity of undifferentiated mesenchyme. In addition, it acquires a secondary attachment to the ventral abdominal wall, which has a considerable influence on its subsequent

* J. Gillman, *Contr. Embryol. Carneg. Instrn.*, 32, 1948.

movements. At the point where the mesonephric fold bends medially to form the genital cord (p. 207), it becomes connected to the lower part of the ventral abdominal wall by a fold of peritoneum which is termed the *inguinal fold* (fig. 229). The mesenchymal cells included in the inguinal fold form a cord, which extends from that part of the skin which later forms the scrotum, through the inguinal fold and the mesorchium to the lower pole of the testis. This cord later becomes a fibromuscular bundle and is termed the *gubernaculum testis*. It traverses the site of the future inguinal canal, which is formed around it by the muscles of the abdominal wall as they become differentiated. At the end of the second month the caudal part of the ventral abdominal wall is horizontal but, after the return of the intestines to the peritoneal cavity (p. 191), it grows in length and assumes a vertical position. As a result the umbilical artery pulls up a sickle-shaped peritoneal fold, as it runs ventrally from the dorsal to the ventral wall, and this fold forms the medial boundary of a peritoneal fossa into which the testis projects. This fossa is termed the *saccus vaginalis* and its lower end protrudes down the inguinal canal along the gubernaculum, forming the *processus vaginalis*. The lower pole of the testis is retained in apposition with the deep inguinal ring by the gubernaculum until the seventh

FIG. 237.—Part of the tail-end of a human embryo, about six weeks old.
(Drawn from a model by Keibel.)



The model, which has been partly dissected, is seen from the left side.

month, when it suddenly and rapidly passes through the inguinal canal and gains the scrotum. As it descends it is necessarily accompanied by its peritoneal covering and the adjoining peritoneum from the iliac fossa is drawn down into the processus vaginalis. The distal end of the processus vaginalis, into which the testis projects, forms the tunica vaginalis testis, but the portion associated with the spermatic cord in the scrotum and in the inguinal canal normally becomes obliterated.

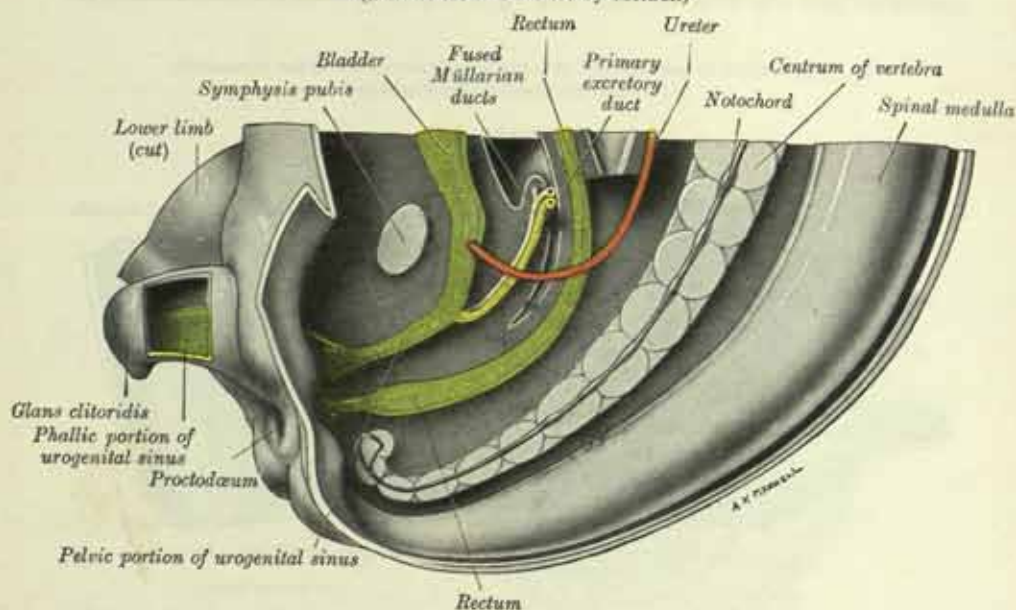
The actual cause of the descent of the testis is still uncertain. It has been ascribed, by different investigators, to shortening and active contraction of the gubernaculum, to increased intra-abdominal pressure, to a simple growth process, and to the effect on the convex surface of the gland of the active contraction of the lower fibres of the internal oblique muscle, which squeezes it through the canal. None of these explanations is entirely satisfactory.

Various abnormalities may occur in connexion with the descent of the testis and the obliteration of the processus vaginalis. The testis may be retained in the abdomen, or it may fail to reach the scrotum and may then lie in any of the following situations:—(1) in the perineum, (2) at the root of the penis, (3) at the superficial inguinal ring, (4) in the upper part of the thigh. These malpositions are associated with certain additional connexions of the bundles of the gubernaculum testis. The largest bundle normally passes to the scrotum and smaller bundles gain attachment to the perineum, the root of the penis, the pubis, the inguinal ligament, and the neighbourhood of the saphenous opening. The testis must follow the processus vaginalis and, should the latter for any reason follow any but the scrotal bundle of the gubernaculum, malposition of the testis will result.

The processus vaginalis may remain completely patent, or its obliteration may be incomplete. When it retains a connexion with the general peritoneal cavity it provides a preformed sac for a potential oblique inguinal hernia. It may be occluded at its upper end and may be shut off from the tunica vaginalis and yet remain patent in the intervening section. The patent portion may become distended with fluid, constituting an encysted hydrocoele of the spermatic cord.

The descent of the ovary.—Like the testis, the ovary lies at a lower level in the adult than it does in the early months of fetal life, but it does not leave the pelvis to enter the inguinal canal save under abnormal conditions. Connected to the medial portion of the mesonephric fold by the mesovarium, which is homologous with the mesorchium, the ovary is also attached to the ventral abdominal wall through the medium of the inguinal fold. In this fold the fibro-muscular gubernaculum develops and, as it traverses the mesonephric fold, it acquires an additional attachment to the cornu of the uterus; its lower portion forms the round ligament of the

FIG. 238.—The tail-end of a human embryo, eight and a half to nine weeks old. (Drawn from a model by Keibel.)



The model has been dissected from the left side to show the structures in and near the median plane. Note that the cloaca has now been separated completely into urogenital and intestinal segments.

uterus and its upper part the ligament of the ovary, these two structures together being homologous with the gubernaculum testis in the male. This new attachment serves to anchor the ovary and to restrict its movements. At first the ovary is attached to the medial side of the mesonephric fold, but owing to the way in which the two mesonephric folds unite to form the genital cord (p. 207) it is found connected to the posterior layer of the broad ligament of the uterus in the adult.

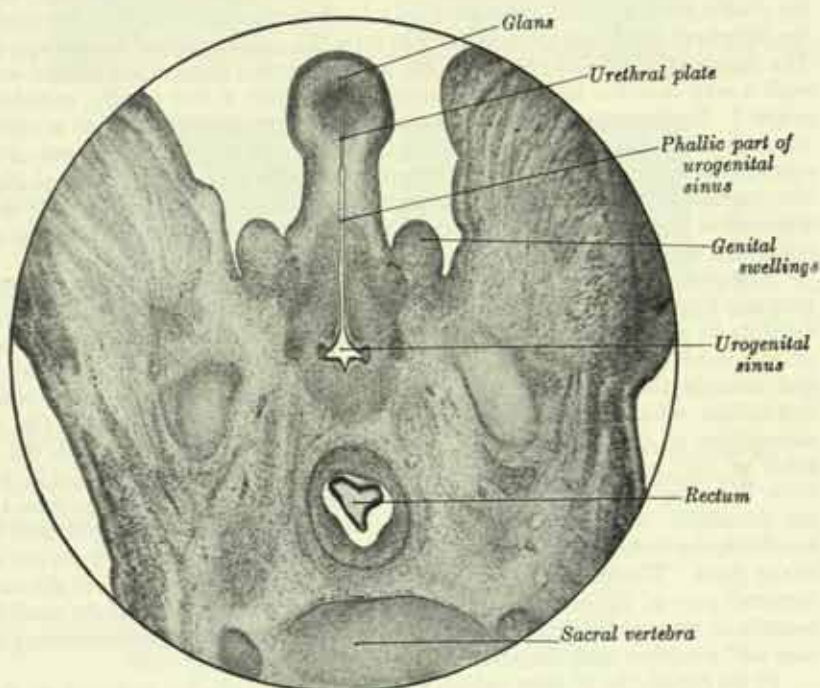
The saccus vaginalis forms in the female as in the male; its prolongation into the inguinal canal, which is termed the *canal of Nuck*, normally undergoes complete obliteration, but it may remain patent and form the sac of an oblique inguinal hernia. At birth the ovary and the corresponding end of the uterine tube lie in the false pelvis, and they do not sink down into the true pelvis until it enlarges sufficiently to contain both them and the bladder together with the other pelvic viscera.

The **urinary bladder** is formed partly from the entodermal cloaca and partly from the ends of the mesonephric ducts. After the separation of the rectum from the cloaca (p. 194), the ventral part of the latter becomes subdivided into three portions: (1) a cephalic *vesico-urethral portion*, continuous with the allantoic canal—into this portion the mesonephric ducts open; (2) a middle, narrow channel,

the *pelvic portion*; and (3) a caudal, deep, *phallic portion*, closed externally by the urogenital membrane (fig. 238). The second and third parts together constitute the *urogenital sinus*. The ureter and the mesonephric duct come to open separately into the vesico-urethral portion (p. 209). The termination of the mesonephric duct is then transferred caudally so that it opens into that part which will form the prostatic urethra. This occurs by the formation of a caudally directed loop of the duct behind the urogenital sinus, followed by absorption of the apposed walls. In this way the mesonephric duct participates in the formation of the trigone of the bladder and dorsal wall of the prostatic urethra. The remainder of the vesico-urethral portion forms the body of the bladder and part of the prostatic urethra; its apex is prolonged to the umbilicus as a narrow canal, termed the *urachus*. In postnatal life the urachus is drawn downwards as the bladder descends, but its blind upper end remains connected to one or both of the obliterated umbilical arteries. Its lumen is retained throughout life, and its lower end frequently communicates with the bladder near its apex.*

The **prostate** arises during the third month as a number of outgrowths from

FIG. 239.—Transverse section through the lower part of the pelvis of a nine weeks old human embryo.



the proximal part of the urethra. These outgrowths, some fourteen to twenty in number, arise mainly from the lateral aspects of the tube, but some develop from its dorsal aspect and a few from its ventral aspect. Most of these outgrowths form caudal to the orifices of the mesonephric ducts, but about one-third occur on the cephalic side. The outgrowths, which are at first solid become tubular and invade the surrounding mesenchyme, which is being differentiated into muscular tissue.

Similar outgrowths occur in the female, but they remain in a rudimentary condition and form the para-urethral ducts.

The *bulbo-urethral glands* in the male, and *greater vestibular glands* in the female, arise as diverticula from the epithelial lining of the urogenital sinus.

The external organs of generation.—These organs, like the genital glands, pass through an indifferent stage before it is possible to recognise distinguishing

sexual characters. A surface elevation, termed the *genital tubercle*, appears at the cranial end of the cloacal membrane and lengthens to form the *phallus*. Within it is a sagittally placed entodermal plate, the *urethral plate* (fig. 239), which grows forwards from the walls of the cloaca and urogenital sinus towards the tip of the organ. The lower margin of the plate is in contact with the ectoderm lining a median groove, the *primary urethral groove*, which has meanwhile developed along the caudal surface of the phallus. The raised margins of the groove are named the *genital folds* (fig. 240). Behind they surround the urogenital membrane and terminate in a transverse ridge immediately in front of the anus.* The rupture of the urogenital membrane provides a common perineal orifice for both the generative and urinary tracts at the base of the phallus. This orifice is bounded at the sides by the genital folds. Meanwhile disintegration of the cells of the urethral plate and contiguous ectoderm occurs, commencing at the base of the phallus and resulting in a deepening of the urethra which is now termed the *definitive urethral groove*.

While these changes are in progress two *genital swellings* (labioscrotal folds) have appeared on each side of the base of the phallus and extend caudally, separated from the genital folds by distinct grooves (figs. 239 and 240).

In the male the phallus enlarges to form the penis and its apex constitutes the glans. The genital swellings meet each other ventral to the anus and unite to form the scrotum. The genital folds fuse with each other from behind forwards enclosing the phallic portion of the urogenital sinus behind to form the bulb of the urethra and the definitive urethral groove in front to form the greater part of the spongy urethra. The fusion of the folds results in the formation of a median raphe and occurs in such a way that the lining of the urethra is mainly, if not wholly, entodermal in origin.† In this way, as the phallus lengthens, the urogenital orifice is carried onwards until it reaches the glans. At the tip of the glans an ingrowth of surface epithelium has occurred to meet the anterior extremity of the urethral plate, the disintegration of which gives rise to a groove which is entirely ectodermal in origin. Closure of this part of the groove gives rise to the terminal part of the urethra contained within the glans.

The glans penis and coronary sulcus are recognisable by the third month. The prepuce begins to develop in the third month, at a time when the urethra still exhibits its primary orifice at the base of the glans. A ridge consisting of a mesodermal core covered by epithelium appears proximal to the coronary sulcus and extends forwards over the glans. Deep to this ridge is a solid lamella of epithelium which extends backwards to the base of the glans. The ventral extremities of the ridge curve backwards to become continuous with the genital folds at the margins of the urethral orifice. As the urethral folds meet to form the terminal part of the urethra the ventral horns of the ridge fuse to form the frenulum. Over the dorsum and sides of the glans, the epithelial lamella breaks down to form the preputial sac and thus free the prepuce from the surface of the glans. Thereafter the prepuce grows forwards as a free fold of skin over the terminal part of the glans. The preputial sac may not be complete until 6 to 12 months or more after birth and, even then, the presence of some connecting strands may still interfere with the retractibility of the prepuce.

In the female the phallus, which exceeds the male phallus in length in the early stages, becomes the clitoris. The genital swellings remain separate as the labia majora and the genital folds also remain ununited, forming the labia minora. The perineal orifice of the urogenital sinus is retained as the cleft between the labia minora, above which the urethra and vagina open. The prepuce of the clitoris develops in the same way as the homologous structure in the male.

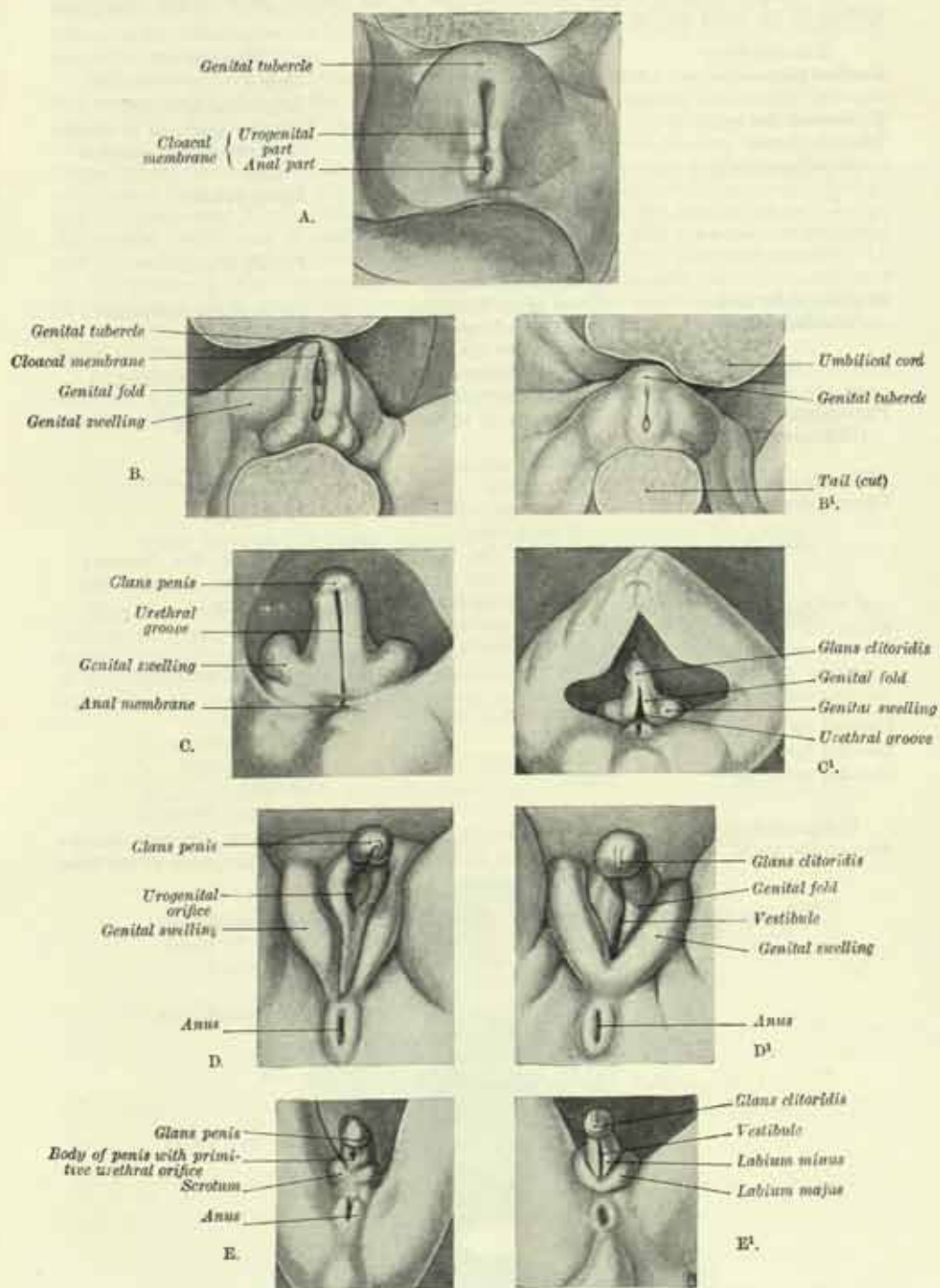
The urethra.—In the female, the whole of the urethra is derived from the vesico-urethral portion of the cloaca (p. 216). It is homologous with that part of the prostatic urethra in the male which lies headwards of the orifices of the prostatic utricle and the ejaculatory ducts.

In the male, the prostatic part of the urethra headwards of the orifice of the prostatic utricle is derived from the vesico-urethral portion of the cloaca and the

* According to Ellsworth M. Tench (*Amer. J. Anat.*, 59, 1936) the genital folds are continuous behind with the anal tubercles, which do not fuse with each other in front of the anus until a later stage.

† T. W. Glenister, *J. Anat. Lond.*, 88, 1954.

FIG. 240.—Stages in the development of the external sexual organs in the male and female. (M. H. Spaulding, *Contr. Embryol. Carneg. Instrn.*, 13, 1921.)



A. Indifferent stage, 8 mm. ($\times 21$). B. Male, 14 mm. ($\times 14.5$). B¹. Female, 15 mm. ($\times 11$). C. Male, 21 mm. ($\times 12$). C¹. Female, 21 mm. ($\times 7$). D. Male, 45 mm. ($\times 8$). D¹. Female, 49 mm. ($\times 9$). E. Male, 45 mm. ($\times 3.5$). E¹. Female, 51 mm. ($\times 4$).

incorporated caudal ends of the mesonephric ducts. The remainder of the prostatic part, the membranous part and probably the part within the bulb, are all derived from the urogenital sinus (p. 216). The succeeding portion, as far as the glans, is

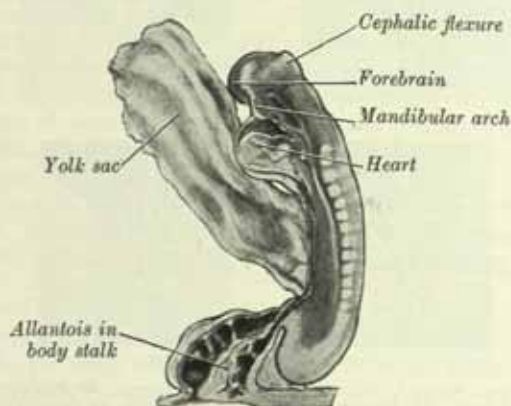
formed by the fusion of the genital folds, while the section within the glans is formed in the way described above.

The subjoined table shows the homologies of the various parts of the urogenital system in the male and in the female (fig. 234).

INDIFFERENT	MALE	FEMALE
Genital gland	Testis	Ovary
Gubernacular cord	Gubernaculum testis	{ Ligament of ovary
Mesonephros	(?) Appendix of epididymis	{ Round ligament of uterus
(Wolffian body)	Efferent ducts of testis	(?) Appendices vesiculosæ
	Coni vasculosi of head of epididymis	Epoöphoron
	Paradidymis	Paroöphoron
Mesonephric duct	Ductuli aberrantes	
(Wolffian duct)	Duct of epididymis	Duct of epoöphoron
	Ductus deferens	
	Ejaculatory duct	
	Part of bladder and prostatic urethra	Part of bladder and urethra
Paramesonephric ducts	Appendix of testis	Uterine tubes
(Müllerian ducts)		Uterus
Allantoic canal	Prostatic utricle	Vagina
Cloaca, dorsal portion of	(?) Urachus	(?) Urachus
	Rectum and upper part of anal canal	As in male
ventral portion of	Most of the urinary bladder and part of prostatic urethra	Most of the urinary bladder, and the urethra
urogenital sinus	Prostatic urethra (below prostatic utricle)	
	Bulbo-urethral glands	Greater vestibular glands
Genital swellings	Remainder of urethra	Vestibule
Genital folds	Scrotum	Labia majora
Genital tubercle	Ventral aspect of penis	Labia minora
	Penis	Clitoris

Congenital defects of the urethra, due to arrests of development, are not uncommon in the male. The urethra may open on the ventral aspect of the penis at the base

FIG. 241.—A human embryo with 13 somites. Viewed from the left side. (G. L. Streeter, *Contr. Embryol. Carnegie. Instrn.*, 30, 1942.) ($\times 12.5$)



Note.—This embryo has a crown-rump length of 2.5 mm. and its age is estimated at 23 days. The dark areas in the body stalk are due to the presence of blood in the umbilical vessels.

of the glans, and the portion of the urethra which is normally within the glans is absent. This constitutes the simplest form of *hypospadias*. In more severe cases

the genital folds fail to fuse, and the urethra opens on the ventral aspect of a malformed penis just in front of the scrotum. A still greater degree of this malformation is accompanied by failure of the genital swellings to unite with each other. In these cases the scrotum is divided and, as the testes are frequently undescended, the resemblance to the labia majora is very striking. Male children suffering from this deformity are often mistaken for girls.

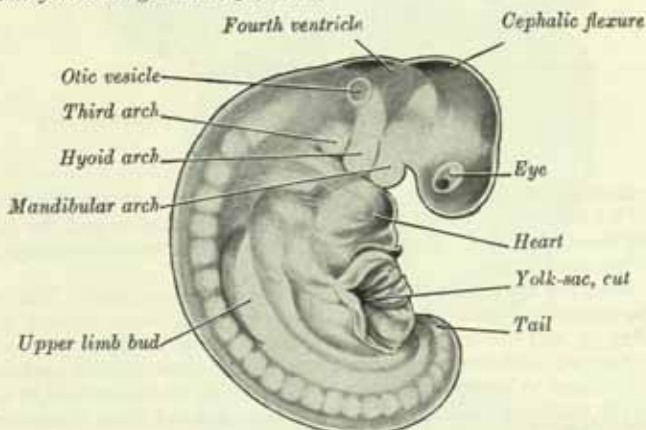
Maldevelopment of the cloacal or urogenital membranes is a less common condition but two varieties of it can be distinguished. (1) In *extroversion of the bladder* (ectopia vesicae) * the lower part of the anterior abdominal wall is occupied by an irregularly oval area, covered with mucous membrane, on which the two ureters open. Around its periphery this extroverted area, which is lined by transitional epithelium, becomes continuous with the skin. (2) In *extroversion of the cloaca* the condition is very similar, but is complicated by the presence of intestinal openings in the median plane. In (2) the cloacal membrane is probably abnormally elongated and ruptures prematurely and throughout its whole extent, prior to the formation of the urorectal septum. In (1) the maldevelopment occurs after the separation of the ventral from the dorsal part of the cloaca. The urogenital membrane extends further headwards than it does in normal cases and the genital tubercle forms at its caudal limit. Rupture of the membrane throws the bladder open to the exterior.

In *epispadias* the urethra opens on the dorsal aspect of the penis at its junction with the anterior abdominal wall. No entirely satisfactory explanation has yet been suggested for this anomaly.

THE FORM OF THE EMBRYO AT DIFFERENT STAGES OF ITS GROWTH

Our knowledge of the earliest stages of the development of the human embryo has undergone a very rapid expansion during recent years (footnotes, pp. 66 to 71) and a summary has already been given (pp. 68 to 73). It will be remembered that by the end of the second week after fertilisation the ovum consists of a hollow blastocyst, containing the amnio-embryonic and the yolk-sac vesicles, and that the embryonic area, at

FIG. 242.—Right lateral view of a human embryo, with 28 pairs of somites. CR = length = 4 mm. ($\times 6.12.5$.) Estimated age, 27 days. (G.L. Streeter, *Contr. Embryol. Carneg. Instn.*, 30, 1942.)



first circular and later oval, is formed where the two vesicles come into contact with each other. At this stage the embryo has the form of a flat or gently curved plate.

During the third week differentiation commences in the embryonic area. The primitive streak and node, the head process and the neural groove appear. The allanto-enteric diverticulum is present and, by the end of the period, head and tail folds are in process of formation (fig. 81) and the first somites appear. The cloacal membrane can be identified.

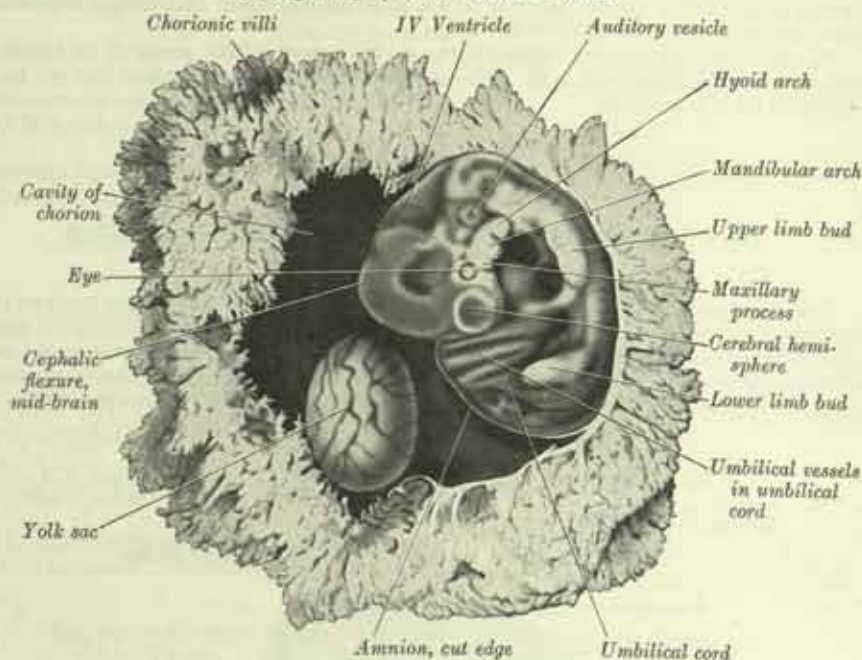
During the fourth week (figs. 241 and 242) the head and tail folds are completed.

* G. M. Wyburn, *J. Anat.*, Lond., 71, 1937.

The primary cerebral vesicles and the optic vesicles can be recognised; the neural groove commences to close in the first half of the period and the process is completed before its end. The auditory vesicle appears, but as yet the face is unrecognisable. The position of the neck is indicated by the branchial arches and grooves, and the rudiments of the limb-buds can be identified. The heart forms a prominent elevation, immediately caudal to the stomodæum, and segmentation of the mesoderm, which may begin at the end of the third week, is continued and completed. The vitello-umbilical veins communicate with the common sinu-atrial chamber, the heart begins to beat and the embryonic circulation is established; at the end of the period the embryo is about 3.5 mm. long.

In the fifth week the embryo becomes markedly curved on itself and becomes more definitely pinched off from the yolk-sac. The cervical flexure of the neural tube can be recognised. The lens vesicle has closed and is separated from the covering ectoderm.

FIG. 243.—A human embryo, about 8 mm. long. Sixth week. Drawn from a stereoscopic photograph taken before fixation.



The olfactory placodes are present, and the maxillary and fronto-nasal processes can be identified. The limb-buds lengthen, the joint flexures appear and the hands and feet can be recognised (fig. 243). By the end of the period the crown-rump length of the embryo has reached 7 mm.

In the sixth week the curvature of the embryo is further increased. The head is in contact with the umbilical cord and may almost meet the long, curved tail. The olfactory pits deepen, and the maxillary, lateral nasal and globular processes begin to fuse. The liver forms a surface prominence between the heart and the umbilical cord. The limb-buds increase in length and three segments can be recognised in each. By the end of the sixth week the U-loop of gut has been extruded from the abdomen and the embryo has increased to 13 mm. crown-rump length.

In the seventh and eighth weeks the flexure of the head is gradually reduced and the neck is somewhat lengthened. The upper lip is completed and the nostrils are directed forwards; the palate is not completely developed. The eyelids are present in the shape of folds above and below the eye, and the different parts of the auricle are distinguishable. The external genitalia are present and may show sexual differences by the end of the seventh week. The tail begins to disappear. The fingers and toes can be recognised. By the end of the eighth week the embryo has attained a crown-rump length of nearly 30 mm. and now passes into the fetal period.

In the third lunar month the head is extended and the neck is lengthened. The eyelids meet and fuse, remaining closed until the end of the sixth month. The

FIG. 244.—Human embryo, about 9 mm. long. Sixth week. (Drawn from a stereoscopic photograph.)

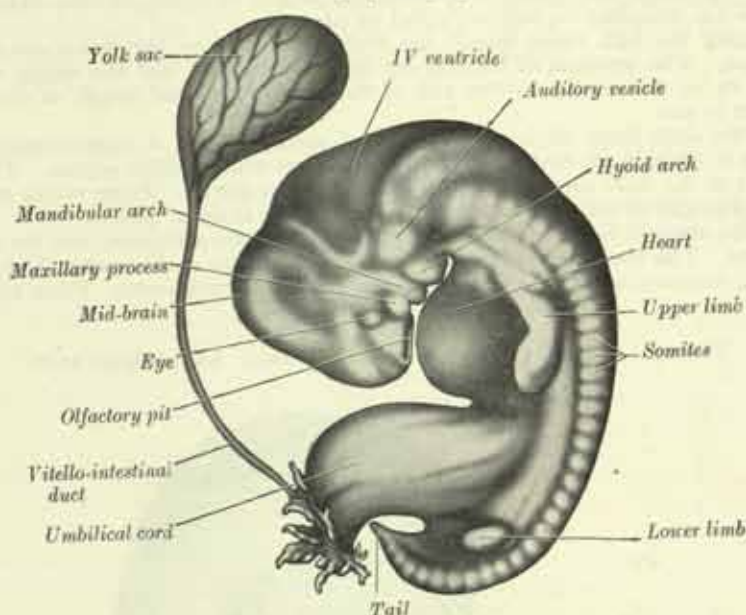
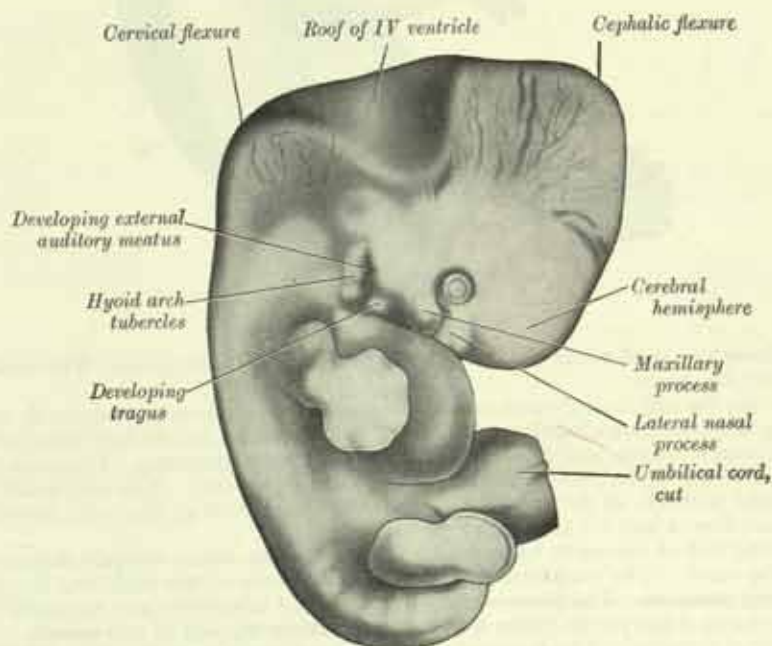


FIG. 245.—Human embryo, about 15 mm. long. Seventh week. (Drawn from a stereoscopic photograph.)



limbs are well developed and nails appear on the digits. The normal umbilical hernia is reduced and by the end of this month the crown-rump length of the foetus is about 55 mm.

In the fourth lunar month lanugo appears on the body, and by the end of the month the foetus has reached a crown-rump length of about 10 cm., and a total length—i.e. including the legs—of about 15 cm.

During the fifth lunar month the first movements of the foetus are usually observed. The eruption of hair on the head commences, and the vernix caseosa begins to be deposited. By the end of this month the total length of the foetus is about 23 cm.

In the sixth lunar month the deposit of vernix caseosa is considerable. The papillae of the skin are developed and the eyebrows and eyelashes appear. The free borders of the nails project from the corium of the dermis. From vertex to heels the total length of the foetus at the end of this month is about 30 cm.

In the seventh lunar month the pupillary membrane atrophies, and the eyelids are open. The testis descends with the vaginal sac of the peritoneum. The skin is red and wrinkled, giving the foetus a prematurely aged appearance. From vertex to

FIG. 246.—A human embryo, about 30 mm. long. End of eighth week.



heels the total length at the end of the seventh month is about 35 cm. The weight is about 1.5 kilograms.

During the eighth and ninth lunar months the skin is entirely coated with vernix caseosa, and the lanugo begins to disappear. Subcutaneous fat has been developed to a considerable extent, and the foetus presents a plump appearance. The nails reach the ends of the digits, first on the fingers and later on the toes. The total length, i.e. from head to heels, at the end of the ninth month is about 45 cm., and the weight varies between 2 and 2.5 kilograms.

At the end of the tenth lunar month the lanugo has almost entirely disappeared from the trunk. The umbilicus is almost in the middle of the body and the testes are in the scrotum. The foetus weighs from 3 to 3.5 kilograms, and measures from head to heels about 50 cm. when it is born at or about the end of this month.

Period of gestation.—The duration of pregnancy extends from the date of fertilisation of the ovum until the birth of the child. The period usually covers about 266 days, i.e. ten lunar months less 14 days, although it is often described as covering nine calendar months. Children are often born prematurely and, in the eyes of the law, a child is viable if it is born after the end of the seventh calendar month (middle

of the eighth lunar month). Sometimes the pregnancy lasts longer than the period stated and it may be the tenth calendar (eleventh lunar) month before the child is born.

In obstetric practice it is customary to date a pregnancy from the onset of the last menstruation. It has already been explained (p. 92) that the ovum is liberated on, or near, the fourteenth day of the menstrual cycle so that the "menstrual age" of the fetus is about two weeks in excess of the "fertilisation age".

OSTEOLOGY*

The general framework of the body is built up mainly of a series of bones, but these are supplemented in certain regions by pieces of cartilage; this bony and cartilaginous framework constitutes the *skeleton* (fig. 247).

In comparative anatomy the term skeleton has a wider application, for in some of the lower animals hard, protecting and supporting structures are developed in association with the skin. In such animals the skeleton comprises an internal or deep skeleton, termed the *endoskeleton*, and an external or superficial, termed the *exoskeleton*. In the human subject the exoskeleton is very rudimentary, its only important representatives being the nails and the enamel of the teeth, and therefore, in human anatomy, the term skeleton is confined to the endoskeleton; this is divisible into an *axial* part, which comprises the bones of the head and trunk, and an *appendicular* part, which comprises the bones of the limbs.

The bones available for study in articulated skeletons and as separate entities have been subjected to a process of *maceration*, by which they have been denuded of all the structures attached to them, viz., muscles, ligaments, periosteum and articular cartilage. Subsequently they have been allowed to dry for a prolonged period, with the result that the fat in the marrow has drained away and what is left of the marrow itself has shrivelled up, leaving the bone clean, dry and easy to handle. It should be remembered, however, that living bone, as already stated (p. 22), possesses a considerable degree of elasticity, which is lost in the process of preparation.

Functions of bone.—Bones provide the central axis and *give form* to the body. Many of them are adapted to *give support* to the weight of the body, but they may fulfil some additional function, e.g. the thigh bones support the weight of the body in standing, walking and running, but they also *provide the levers* which are essential for locomotion. Other bones *give protection* to underlying or contained structures, e.g., the cranium protects the contained brain, and the sternum and ribs overlie the heart and lungs and give them some measure of protection. Others, again, *afford areas for the attachment of muscles* and provide the levers which facilitate speedy and efficient movements. Bones, therefore, constitute an important part of the locomotor apparatus of the body, but to enable them to function as levers for the production of movements they must be connected by muscles, and movable joints or articulations must be present where individual bones come into contact with one another.

Bones are divisible into four classes: *long, short, flat, and pneumatic*.

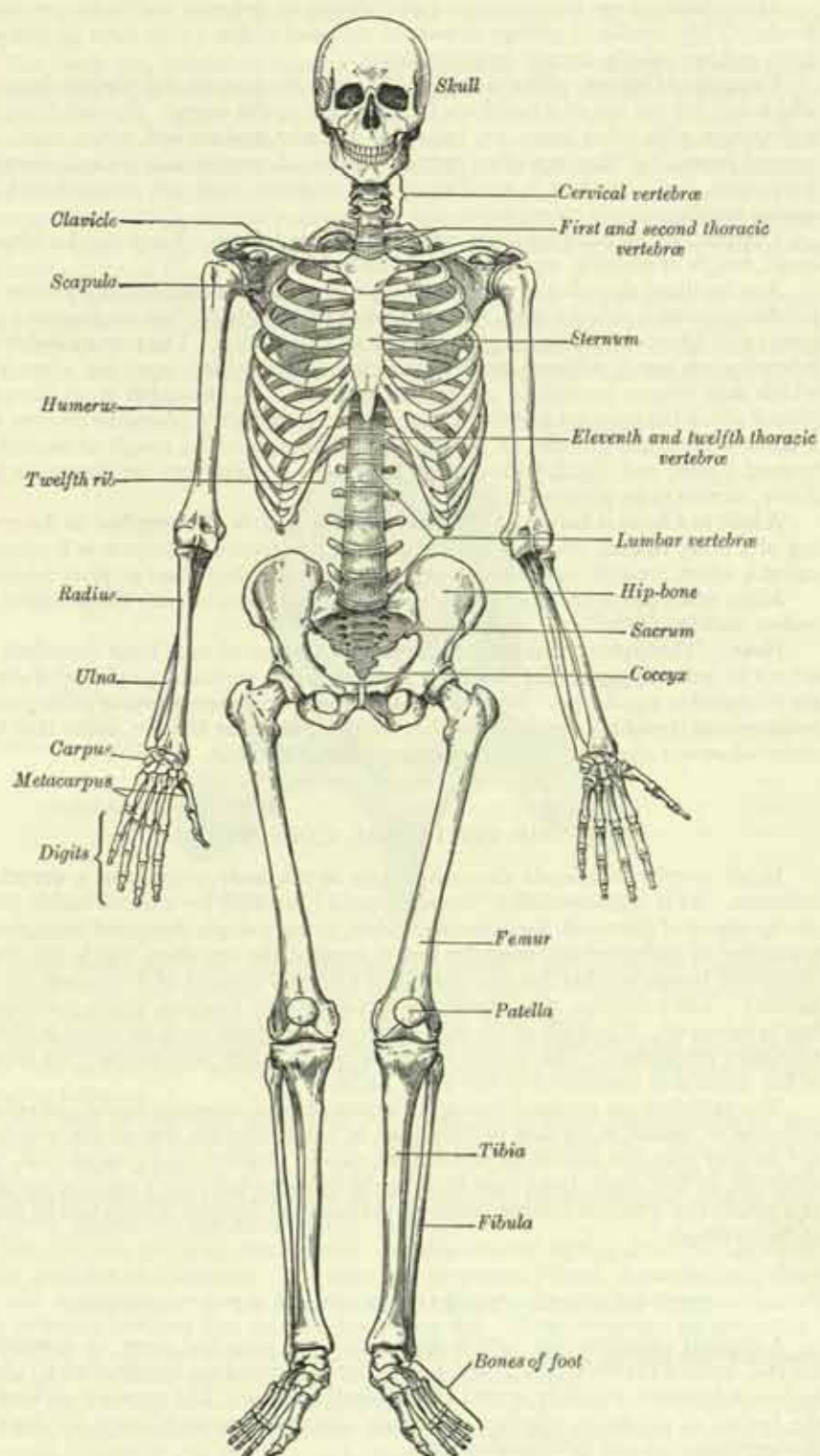
The **long bones** are found in the limbs, where they form levers; each has a shaft and two ends. The *shaft* is tubular, and its central cavity is termed the *medullary cavity*; the wall consists of dense, compact substance of considerable thickness in the middle part of the shaft of the bone, but becoming thinner towards the ends; projecting into the medullary cavity there is some spongy substance, scanty in the middle of the shaft of the bone but plentiful towards the ends. The *ends* are usually expanded for purposes of articulation and muscular attachment; they consist of spongy substance covered by thin compact bone, and are usually developed from one or more secondary or *epiphyseal* centres of ossification (p. 29). The medullary cavity and the spaces in the spongy substance are filled with marrow (*medulla ossium*) (p. 50).

The **short bones**.—Where a part of the skeleton is intended for strength and compactness combined with limited movement it is constructed of a number of short bones, as in the *carpus* and *tarsus*. These bones consist of spongy substance surrounded by a thin crust of compact bone.

The **flat bones**.—Where the principal requirement of the skeleton is to protect delicate structures or provide broad surfaces for muscular attachment the bones are expanded into plates, as in the skull and the shoulder-blades, and are composed of two thin layers of compact bone separated by a variable quantity of spongy substance. In the cranial bones the layers of compact bone are known as the *tables* of the skull; the outer table is thick and tough, the inner thin, dense and brittle. The intervening

* The structure, physical properties, development and growth of bone, its blood-supply and its nerve-supply, are dealt with on pages 22 to 31.

FIG. 247.—Front view of the skeleton. The right hand is in the prone position, the left in the supine position.



spongy substance is called the *diploe*, and this, in certain regions of the skull, undergoes absorption, and air-filled spaces, termed *sinuses*, are left between the tables of the skull. Such bones are termed **pneumatic bones**.

Many bones, from their peculiar form, cannot be grouped under the preceding heads. They consist of spongy substance enclosed within a thin layer of compact bone and are usually termed *irregular bones*.

Features of bones.—The surfaces of bones present many and variable features, which call for the use of a number of special descriptive terms. Smooth areas for articulation with other bones are known as *articular surfaces* and, when small, are termed *facets*, but they are often termed *foveae*. A *condyle* is a smooth rounded projection, and a *trochlea* is a pulley-shaped surface; both are covered with articular cartilage in the recent state.

Depressions on bony surfaces are usually termed *fossæ*. They may be large or small, rough or smooth, non-articular or articular.

Any localised elevation or projection on a bony surface constitutes a *process*. A pointed process is called a *spine*, but the term is frequently applied to elongated processes with blunt extremities, e.g. the spines of the vertebræ. The terms *tubercle* and *tuberosity* are used, without much distinction, for localised, rounded elevations, which may possess smooth or roughened surfaces. An *epicondyle* is an elevation placed above the articular surface of a condyle. A *hamulus* is a hook-like process, and a *cornu* a horn-like process. A sharp, distinct ridge, whether rough or smooth, is termed a *crest*, and if it is wide enough to possess borders they are known as *lips*. A low, narrow ridge is termed a *line*.

A hole in a bone is known as a *foramen*, and the term is often applied to the opening of a bony tunnel, which is termed a *canal*. A groove or furrow is frequently called a *sulcus*, a notch an *incisura*, a gap a *hiatus*, and a thin sheet or plate a *lamina*.

Many other terms are employed occasionally, but those already defined have the widest use.

Note.—Throughout this section the *general features* of each bone described are set out in ordinary type; the *particular features*, which contain a good deal of detail, are relegated to small type. *Junior students should restrict their attention to the general features, and should not concern themselves with the particular features, unless they have dissected, or are dissecting, the corresponding part of the body.*

THE VERTEBRAL COLUMN

In all vertebrate animals the central axis of the body consists of a **vertebral column**. As it is essential that provision should be made for a considerable range of movement of the trunk, the column consists, not of a single elongated bone, but of a number of independent, irregular bones, termed the *vertebræ*, which are firmly connected to one another but are capable of a limited amount of movement on one another. The provision of a central axis is not the only function which the column has to subserve. It is built up so as to surround the spinal cord, to which it affords necessary protection. The human vertebral column must also support the weight of the trunk and transmit it to the lower limbs.

The vertebræ are grouped under the names *cervical*, *thoracic*, *lumbar*, *sacral* and *coccygeal* or *caudal*, according to the region in which they lie, but all the vertebræ, not only of man but also of all vertebrate animals, conform to a general plan, and although, at first sight, there may be little resemblance between a cervical vertebra of a giraffe and a human lumbar vertebra, the essential features of both will be found to be identical.

THE GENERAL CHARACTERISTICS OF A VERTEBRA

A **typical vertebra** (fig. 248) is made up of two principal parts, an anterior or ventral, termed the *body*, and a posterior or dorsal, termed the *vertebral arch*; these enclose a foramen, which is named the *vertebral foramen*. The opposed surfaces of the bodies of adjoining vertebræ are firmly connected to each other by discs of fibrocartilage, termed *intervertebral discs*.

In the articulated column the bodies and the intervertebral discs form a continuous pillar, which constitutes the central axis of the body and, in man, supports

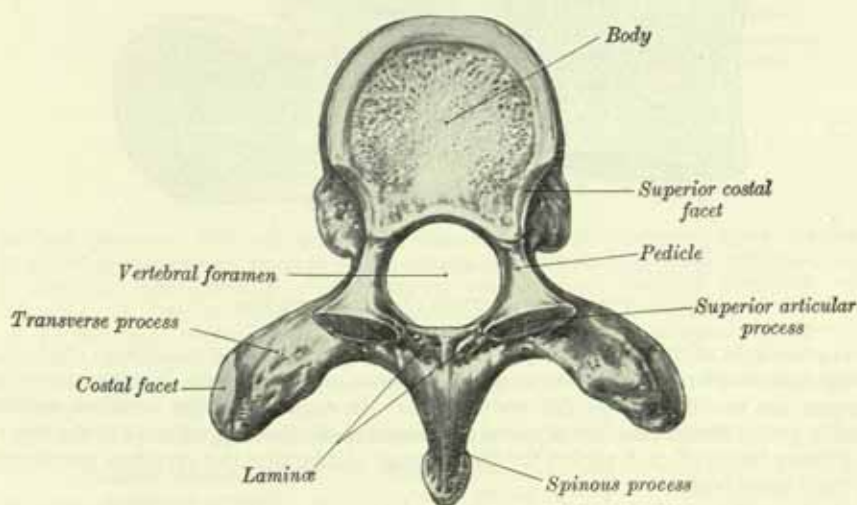
and transmits the weight of the head and trunk. The vertebral foramina, placed one above another, constitute a canal in which the spinal medulla is lodged and protected. Between contiguous vertebræ two *intervertebral foramina*, one on each side, open into the canal and serve for the transmission of the spinal nerves and vessels.

The **body** of a vertebra is more or less cylindrical, but is subject to a wide range of variation in size and shape in different animals and in different regions of the same animal. Its upper and lower surfaces are flattened and roughened to give attachment to the intervertebral discs. In front, it is convex from side to side and gently concave from above downwards; behind, it is flattened or slightly concave from side to side, and flat from above downwards. On its anterior surface there are a few small apertures for the passage of nutrient vessels; on its posterior surface there is a large irregular aperture (occasionally more than one) for the exit of the basivertebral veins (fig. 249).

The **vertebral arch** has a pair of *pedicles* and a pair of *laminae*; it supports seven processes, viz., four *articular* and two *transverse processes* and a *spine*.

The *pedicles* are a pair of short, thick processes, which project backwards from the body at the junctions of its lateral and posterior surfaces. The concavities above

FIG. 248.—A typical thoracic vertebra. Superior aspect.



and below the pedicles are named the *vertebral notches*; and when the vertebræ are articulated with one another, the notches of contiguous vertebræ form the *intervertebral foramina*, to which reference has already been made.

The *laminae* are broad plates directed backwards and medially from the pedicles. They fuse in the spine posteriorly, and so complete the posterior boundary of the vertebral foramen.

The *spine* is directed backwards and downwards from the junction of the laminae, and serves for the attachment of muscles and ligaments. The spines are subject to great variations in size, shape and direction; they provide a series of levers for the movement of extension, or straightening, of the vertebral column and, to a lesser degree, for the movement of rotation.

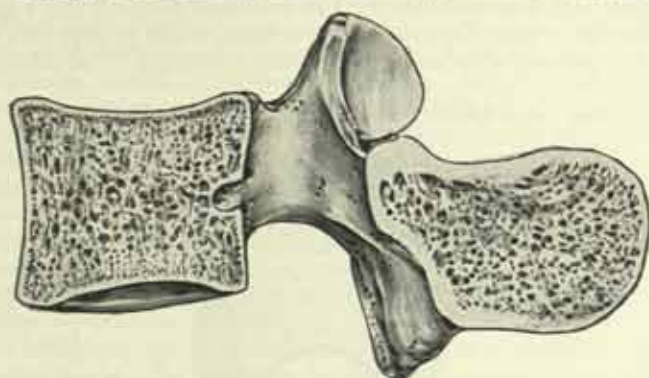
The *articular processes*, two superior and two inferior, spring from the junctions of the pedicles and laminae. The superior processes project upwards, and their articular surfaces face more or less backwards; the inferior project downwards, and their articular surfaces face more or less forwards. These processes meet the corresponding processes of the adjoining vertebræ and, while permitting a certain degree of movement, definitely control and restrict its range.

The *transverse processes* project laterally from the junctions of the pedicles and laminae; they serve for the attachment of muscles and ligaments and are the levers by means of which the rotatory and lateral movements of the vertebræ can be effected. In addition, in the thoracic region they articulate with and limit the movements of the ribs.

The *costal elements* develop as essential constituent parts of each vertebral arch. In certain regions (in man, the thoracic region only) they become independent units—the *ribs*—which articulate with the vertebral column. In other regions they remain stunted and, almost unrecognisable in form, become fused with the vertebrae. Originally protective in function, in higher forms they also act as levers which play an important part in the movements of respiration.

Structure of a vertebra (fig. 249).—The body of a vertebra is composed of spongy substance covered by a thin coating of compact bone, which presents numerous orifices for the passage of vessels; the interior of the body is traversed by one or two large canals, for the transmission of veins, which converge towards the large aperture on the posterior surface. On the upper and lower surfaces of the body the coating of compact bone is thinner than elsewhere, but, in the vertebral arch and the processes projecting from it, it is considerably thicker than it is in the body.

FIG. 249.—A median sagittal section through a lumbar vertebra.



THE INDIVIDUAL VERTEBRÆ

In the light of this description of a typical vertebra it is now possible to study the individual vertebrae of the human vertebral column, and observe how the essential features are modified in the different regions. In each region the vertebrae exhibit certain group characters, but atypical characters make their appearance at the upper and lower limits of each region for the purpose of adapting the vertebrae concerned to their neighbours.

In man the cervical vertebrae are seven in number; the thoracic, twelve; the lumbar, five; the sacral, five; and the coccygeal, four; making a total of thirty-three. The cervical, thoracic and lumbar vertebrae are separate bones throughout life and are therefore known as the *movable vertebrae*; the sacral and coccygeal, on the other hand, are termed *fixed vertebrae*, because, owing to the necessity for stability in this part of the column in man, they are united in the adult to form two bones, viz. the *sacrum* and the *coccyx*.

THE CERVICAL VERTEBRÆ [VERTEBRÆ CERVICALES]

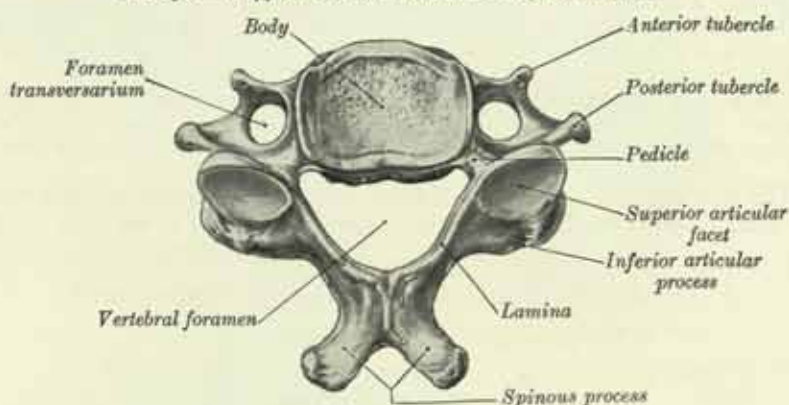
The **cervical vertebrae** (figs. 250, 256), seven in number, are the smallest of the movable vertebrae and can be identified easily owing to the peculiarity of their transverse processes, each of which is perforated by a foramen. The first, second and seventh cervical vertebrae present special distinguishing features, but the remaining four conform to a common type.

A typical cervical vertebra.—General features.—The body is small and is broader from side to side than from before backwards. The *vertebral foramen* is large in proportion to the size of the body and it is triangular in outline. These two features are accounted for, in part, by the direction of the *pedicles*, which project laterally as well as backwards (fig. 250). The superior and inferior vertebral notches are almost equal, for the pedicle is attached to the body nearly midway between its upper and lower borders. The *laminae* are relatively long and narrow, and are thinner above than below. The *spine* is short and bifid and its terminal tubercles are

often unequal in size. The *superior* and *inferior articular processes* form an *articular pillar*, which projects laterally at the junction of the pedicle and lamina. The *transverse process* is pierced by the *foramen transversarium* (fig. 250). It consists of an anterior and a posterior root, connected to each other on the lateral side of the foramen transversarium by a bar of bone, often termed the *costotransverse bar*. The anterior root, the costotransverse bar, the posterior tubercle and the immediately adjoining part of the posterior root are homologous with the rib in the thoracic region; the rest of the posterior root is the homologue of the thoracic transverse process.

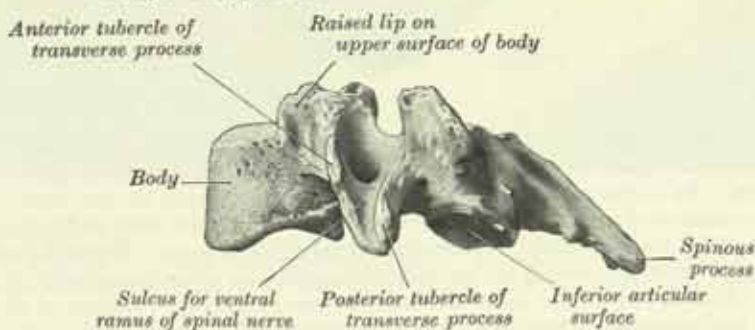
Particular features.—The *anterior surface of the body* is convex from side to side, and its upper and lower borders give attachment to the fibres of the anterior longi-

FIG. 250.—A typical cervical vertebra. Superior aspect.



tudinal ligament. On each side of the ligament a slight depression gives attachment to fibres of the vertical portion of the longus cervicis muscle. The *posterior surface* is flattened and presents near its centre two or more vascular foramina, which transmit the basivertebral veins. Its upper and lower borders give attachment to the posterior longitudinal ligament. The *superior surface* is concave transversely and has an upwardly projecting lip on each side (fig. 250); its anterior border may be slightly bevelled. The inferior surface is saddle-shaped, being convex

FIG. 251.—A typical cervical vertebra. Left lateral aspect.



from side to side and concave from before backwards. Its bevelled lateral border is occasionally separated from the projecting lip of the upper surface of the vertebra below by a small cleft in the intervertebral disc which appears at the age of 9 or 10 years* and has hitherto been described inaccurately as a synovial joint. The anterior border of the lower surface projects downwards and hides the intervertebral disc. The upper borders of the *laminae* and the lower part of their anterior surfaces give attachment to the ligamenta flava. The *spinous processes* give attachment to the ligamentum nuchae and to a number of the deep muscles of the back of the neck, viz. semispinalis thoracis, multifidus, interspinales, spinalis cervicis and semispinalis cervicis.

The *articular pillars* of the third and fourth cervical vertebrae are grooved on their lateral aspects by the dorsal rami of the third and fourth cervical nerves, which

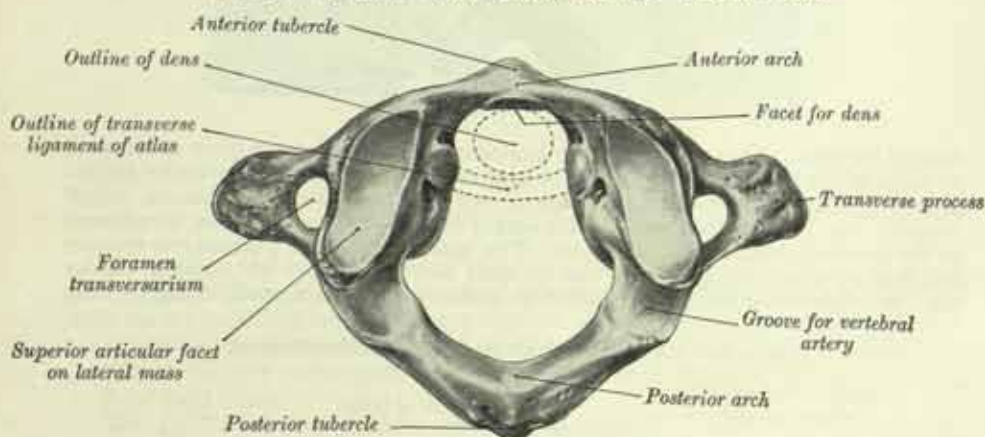
* G. Tondury, *Z. Anat. Entw. Gesch.*, 112, 1943.

pass backwards across them. The superior articular facets are flat and oval in outline; they are directed backwards and upwards. The inferior articular facets, similar in shape, are directed forwards and downwards. In all but the seventh cervical vertebra the **foramen transversarium** transmits the vertebral artery and veins and a branch from the inferior cervical ganglion of the sympathetic trunk. The anterior root of the **transverse process** ends in a rough tubercle, which gives attachment to the scalenus anterior, the longus capitis and the oblique portions of the longus cervicis muscles. The anterior tubercle of the transverse process of the sixth cervical vertebra is enlarged and lies posterior to the common carotid artery, which can be compressed against it. It is therefore termed the *carotid tubercle*. The *costotransverse bar* is oblique in the third cervical vertebra, passing downwards, backwards and laterally; in the fourth also it is oblique, but it is slightly grooved by the emerging ventral ramus of the fourth cervical nerve. In the fifth, the groove is deeper, and in the sixth it is conspicuously wide and shallow. The posterior root of the transverse process terminates laterally in a rounded tubercle, which lies lateral to the anterior tubercle and at a lower level in all except the sixth, in which the two tubercles lie approximately on the same plane.

The posterior tubercles give attachment to a number of muscles, including levator scapulae, scalenus medius (which extends forwards on to the costotransverse bar), scalenus posterior, splenius cervicis, longissimus cervicis and costocervicalis.

The first cervical vertebra.—General features : The first cervical vertebra (fig. 252) is named the **Atlas**, because it supports the globe of the head. It differs

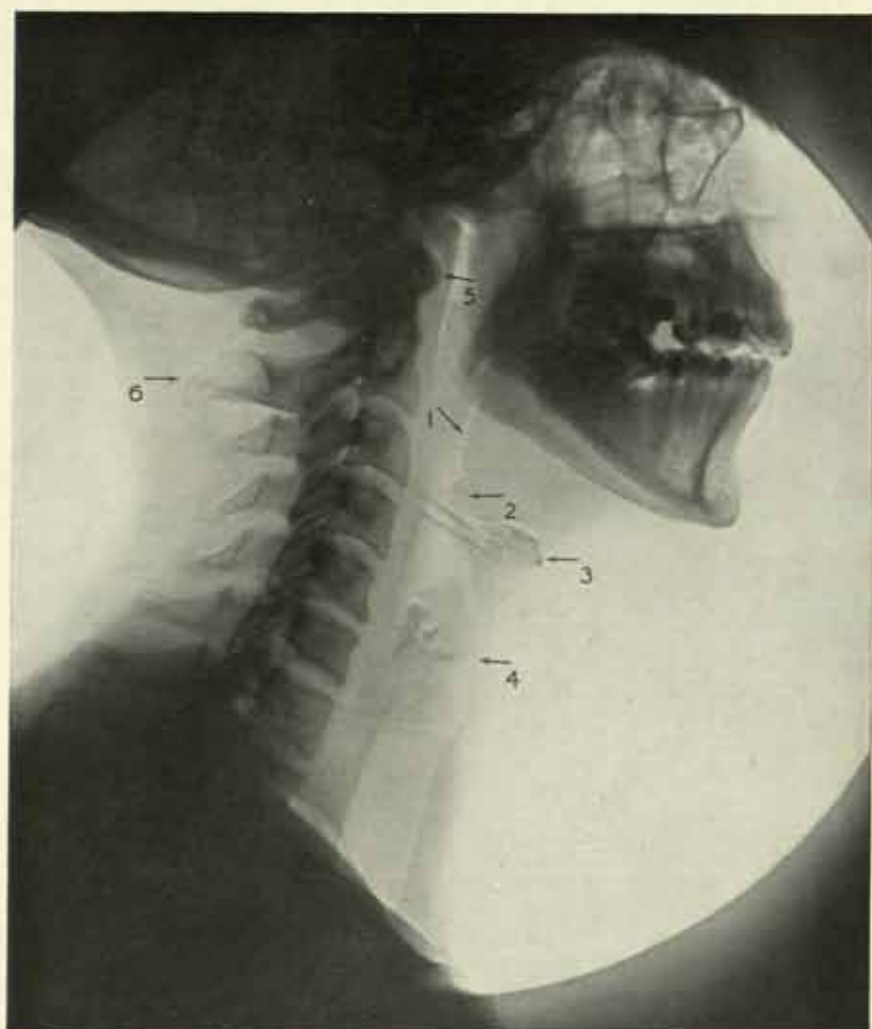
FIG. 252.—The first cervical vertebra, or atlas. Superior aspect.



from all the other vertebrae in having no body, and this is due to the fact that the centrum (p. 249) of the atlas has fused with the centrum of the second cervical vertebra. In addition, it has no spine. The atlas consists of two bulky *lateral masses*, connected to each other in front by a short *anterior arch*, and behind by a long, curved, *posterior arch*. It therefore forms a ring of bone. When the atlas and the second cervical vertebra are articulated together, an upward projection from the latter, which is termed the dens (odontoid process) and is the centrum of the atlas, comes into position behind the anterior arch, and the resemblance to a vertebra is restored (fig. 252).

The *anterior arch* is slightly curved from side to side, with a forward convexity which is accentuated by the presence of a roughened, *anterior tubercle*. Its posterior surface is marked by a median, oval or circular facet, which articulates with the front of the odontoid process. The *lateral mass* is set obliquely, and its long axis runs forwards and medially. Its upper surface forms an elongated, concave facet for articulation with the prominent condyle of the occipital bone of the skull. The inferior surface bears a nearly circular facet, flattened or gently concave, for articulation with the superior facets of the second cervical vertebra. The *posterior arch* forms about two-fifths of the ring. Its upper surface shows a wide groove immediately behind the lateral mass and its spinous process is represented by a small, rough *posterior tubercle*. The *transverse process* is unusually long (fig. 256) and, as a result,

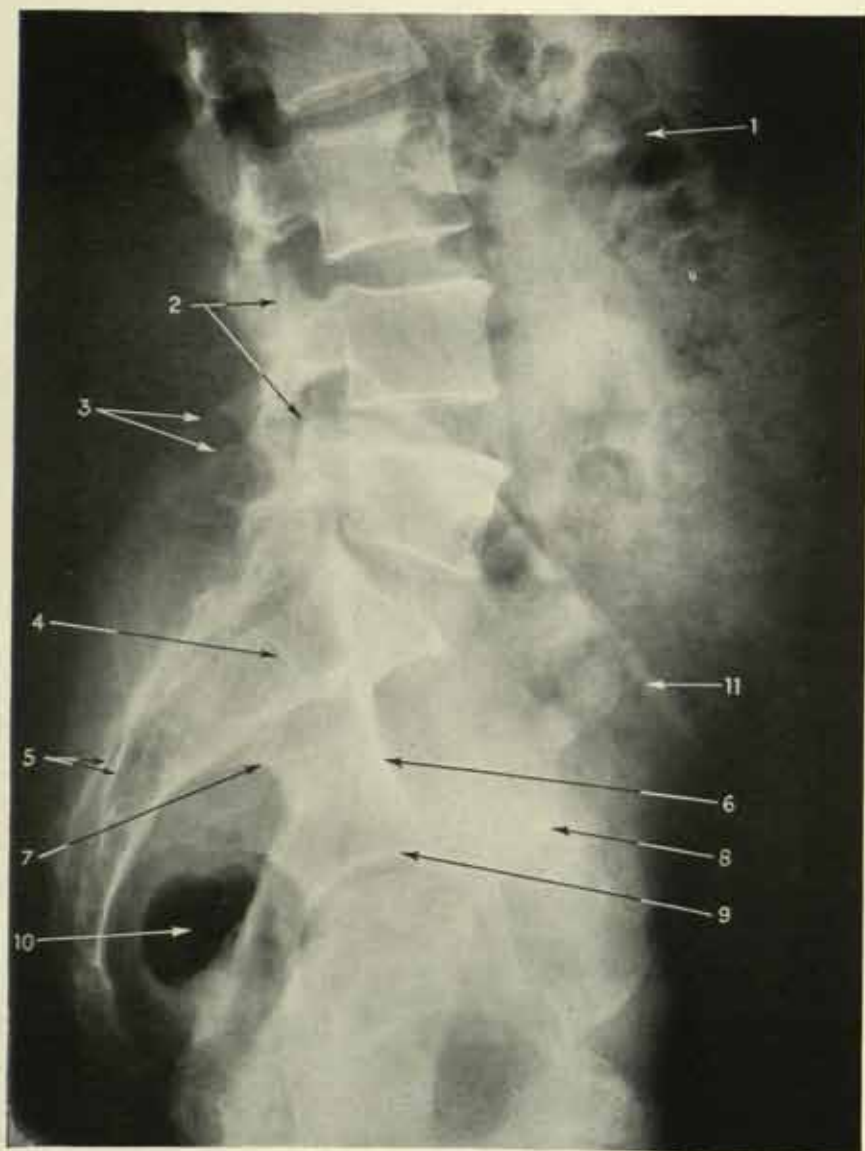
PLATE I



Lateral radiograph of the neck. Positive print. The cervical curve of the vertebral column is well shown. The arrows point, 1, to the pharyngeal part of the tongue : 2, to the epiglottis : 3, to the body of the hyoid bone : 4, to the thyroid cartilage, which is undergoing calcification : 5, to the anterior tubercle of the atlas : and 6, to the spinous process of the axis.

In front of the body of the first thoracic vertebra, a small part of the apex of the lung shows as a narrow, clear area which crosses the opacity caused by the œsophagus and encroaches very slightly on the broad clear area caused by the presence of air in the trachea.

PLATE II



Oblique right lateral view of lumbar part of vertebral column in a youth of 17 years.

1. Gas in right colic flexure. Note succulations of colon. 2. Joints of lumbar vertebral arches. 3. Iliac crests, posterior parts. 4. Intervertebral disc between S.1 and S.2. 5. Edges of sacral hiatus. Note that the laminae of S.3 are not united in this patient. 6. Iliac part of arcuate line of pelvis, which lies in the line of transmission of weight to the acetabulum (9) and the head of the femur. 7. Edge of greater sciatic notch. 8. Anterior inferior iliac spine. 9. Margin of acetabulum. 10. Gas in rectum. 11. An artefact. Note that the anterior superior iliac spine lies immediately to the left of the point of the arrow.

It should be observed that, in lateral views of the vertebral column and the pelvis, some confusion due to overlapping of the right and left sides is unavoidable.

the width of the atlas, measured from tip to tip of its transverse processes, greatly exceeds that of any other cervical vertebra, except the seventh. The length and strength of these transverse processes enables them to function as adequate levers for the rotatory movements of the head, which are effected by the rotation of the skull and the atlas around the pivot provided by the dens of the second cervical vertebra.

Particular features.—The *anterior tubercle* gives attachment to the anterior longitudinal ligament in the median plane: its lateral aspect provides insertion for the upper oblique portion of the longus cervicis muscle. The upper and lower borders of the *anterior arch* give attachment respectively to the anterior atlanto-occipital membrane and the lateral fibres of the anterior longitudinal ligament (anterior atlanto-axial membrane). The superior articular facet of the *lateral mass* is directed upwards and medially and is admirably adapted to the nodding movements of the head, which occur at the atlanto-occipital joints. It is usually constricted near its middle and may be subdivided into two separate areas. Its margins give attachment to the articular capsule of the atlanto-occipital joint. The inferior articular facet is directed downwards, medially and slightly backwards; its margins give attachment to the articular capsule of the atlanto-axial joint. The medial aspect of the lateral mass presents a small roughened tubercle for the attachment of the transverse ligament of the atlas (fig. 493), which passes behind the dens and helps to retain it in place. This ligament divides the ring of the atlas into an anterior, smaller part, which contains the dens (fig. 252), and a posterior, larger part, which transmits the spinal medulla and its membranes. Immediately above the minute tubercle which represents the anterior tubercle of the transverse process of a typical cervical vertebra (*vide infra*), the anterior aspect of the lateral mass gives origin to the rectus capitis anterior muscle.

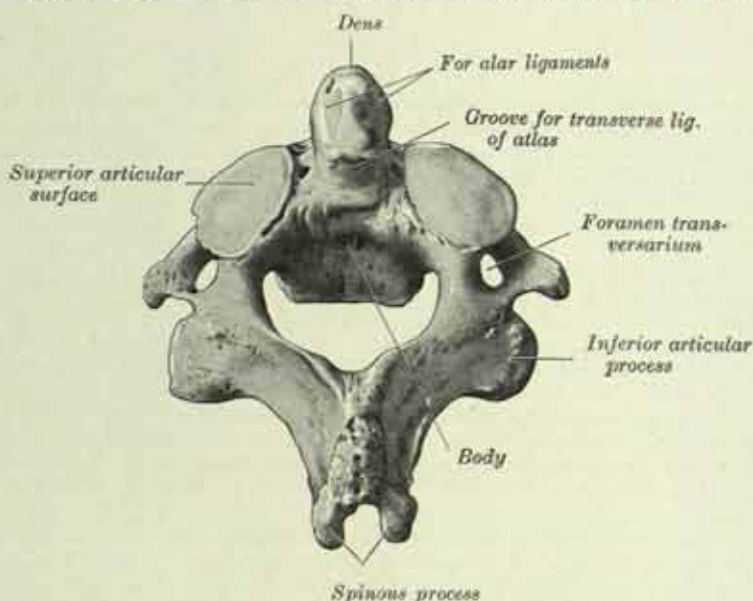
The *posterior tubercle* gives attachment in the median plane to the ligamentum nuchæ, and, on each side, to the rectus capitis posterior minor. Its small size prevents it from interfering with the nodding movements of the head. The upper surface of the *posterior arch* is grooved anteriorly, where it is overhung on each side by the lateral mass. The groove transmits the vertebral artery, which winds backwards and medially round the posterior aspect of the lateral mass (fig. 495). Occasionally the groove for the vertebral artery is converted into a foramen by a bony spicule which arches backwards from the posterior part of the upper surface of the lateral mass. The first cervical nerve, as it emerges from the vertebral canal, intervenes between the vertebral artery and its groove (fig. 495). Behind the groove, on each side, the upper border of the posterior arch gives attachment to the posterior atlanto-occipital membrane; its lower border gives attachment to the highest pair of ligamenta flava.

The length of the *transverse process* and its functional significance have already been considered. Its down-turned extremity, which is homologous with the posterior tubercle of the transverse process of a typical cervical vertebra, may be felt through the skin between the tip of the mastoid process and the angle of the mandible. Its recognition is not easy, for it lies deeply under cover of the parotid gland. Numerous muscles are attached to the process. The rectus capitis lateralis, anteriorly, and the superior oblique muscle of the head, posteriorly, arise from its upper surface: the inferior oblique muscle of the head is inserted into the lower aspect of the extremity of the transverse process, while the levator scapulæ takes origin from its lateral margin and lower border, concealing the uppermost slip of insertion of the splenius cervicis and itself often hidden by the origin of the scalenus medius. A small, often imperceptible, tubercle may be present on the anterior surface of the lateral mass; it represents the anterior tubercle of the typical transverse process, so that the transverse process of the atlas corresponds to the posterior root and the costotransverse bar of the other cervical vertebrae. The ventral ramus of the first cervical nerve runs forwards on the lateral surface of the lateral mass and then turns downwards across the anterior surface of the transverse process. As it does so it is covered by the internal jugular vein, which is crossed in this situation by the accessory nerve and the occipital artery.

The second cervical vertebra.—**General features:** The **second cervical vertebra**, which is named the **Axis** (figs. 253, 254), provides the pivot upon which the atlas, and with it the skull, rotate. It can be distinguished easily from the other vertebrae by means of the strong, toothlike process, named the *dens* (*odontoid process*), which projects upwards from the *body*. The process bears on its anterior surface a small oval facet for articulation with the facet on the posterior surface of the anterior arch of the atlas, and posteriorly it is grooved slightly by a ligament which helps to retain it in position (fig. 253). On each side a large, oval or circular facet is borne on the lateral part of the upper surface of the body and the adjoining part of the pedicle for articulation with the inferior facet of the lateral mass of the atlas. The *laminae*

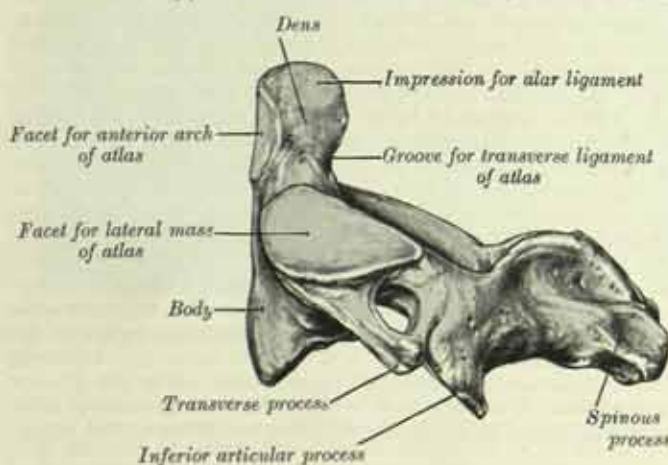
are thick and strong and the vertebral foramen is large and roomy. The *spine* is large and very strong, for it has to provide attachments not only for muscles which

FIG. 253.—The second cervical vertebra, or axis oblique view, from above and behind.



extend the neck but also for muscles which retract the head and rotate it from side to side. The *transverse process*, on the other hand, is very small and its blunt tip, which shows no differentiation into anterior and posterior tubercles, represents the true posterior tubercle only. The foramen transversarium is directed upwards and

FIG. 254.—The second cervical vertebra, or axis. Left lateral aspect.

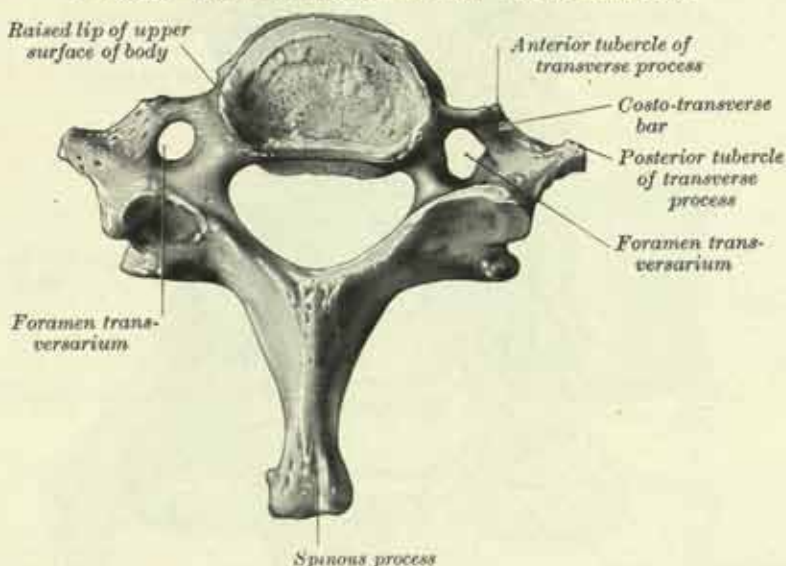


laterally. The *inferior articular facets* look downwards and forwards, as they do in the typical cervical vertebræ.

Particular features.—The *dens* is conical in shape and about 1.5 cm. long; it is constricted below, where it lies in contact posteriorly with the transverse ligament of the atlas. A bursa is usually interposed between the bone and the ligament. The apex is pointed and gives attachment to the apical ligament (p. 471). Below the apex the sides of the process are flattened where the alar ligaments are attached (fig. 253). In structure the dens is composed of more compact bone than the body. The upper

surface of the *body* is obscured by the dens and the superior articular facets. Its anterior surface presents a hollowed out impression on each side of the median plane for the insertion of vertical fibres of the longus colli muscle. The lower border gives attachment to the anterior longitudinal ligament, and its downward projection is a characteristic feature of the axis. Posteriorly the lower border of the body gives attachment to the posterior longitudinal ligament and to the *membrana tectoria* which represents its upward continuation to the occipital bone (p. 471). The *pedicles* are stout and the inferior vertebral notches are deep, in contrast with the superior notches, which are scarcely discernible. The *laminae* are thicker and stronger than the *laminae* of any of the other cervical vertebrae; they provide attachment for the *ligamenta flava*. The coarse, strong *spinous process* gives origin to the inferior oblique muscle, which arises from a rough impression on its lateral aspect, and also to the *rectus capitis posterior major*, which arises from its posterior border. The wide gap at its extremity gives attachment to the *ligamentum nuchae*. In addition it receives the insertions of portions of the *semispinalis cervicis*, *spinalis cervicis*, *interspinalis* and *multifidus*. The *foramen transversarium* is directed upwards and laterally as, owing

FIG. 255.—The seventh cervical vertebra. Viewed from above.



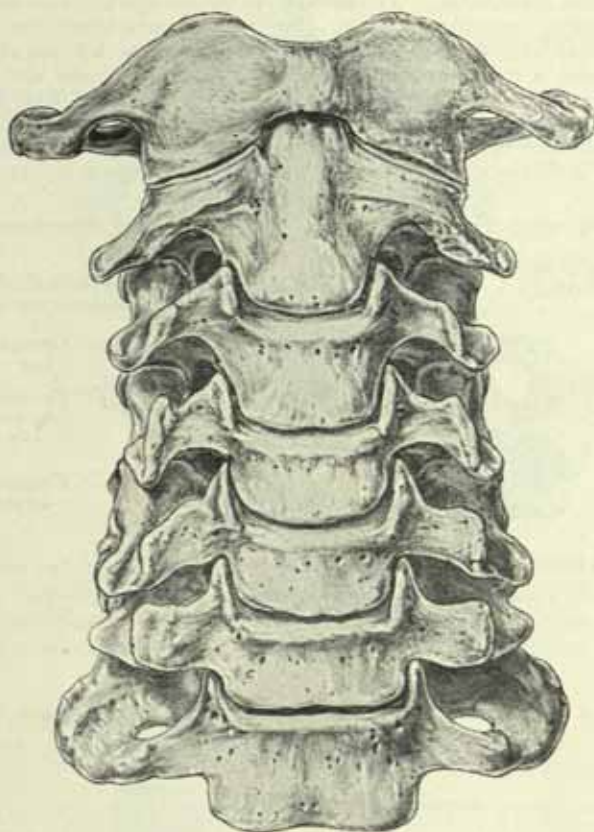
to the difference in length between the transverse process of the axis and that of the atlas, the vertebral artery must deviate in a lateral direction after leaving the axis. The *transverse process* is small, and its anterior tubercle is situated at or near the point where the anterior part of the process reaches the body; in this respect it resembles the anterior tubercle of the transverse process of the atlas. Its extremity gives origin to the *levator scapulae* and, more anteriorly, to the *scalenus medius*; more posteriorly, it gives insertion to the *splenius cervicis*. *Intertransverse muscles* (p. 580) also gain attachment to its upper and lower surfaces.

The seventh cervical vertebra.—General features: The seventh cervical vertebra (fig. 255) is named the *vertebra prominens* because of its long spinous process, the tip of which can be felt through the skin at the lower end of the nuchal furrow. This process is thick and nearly horizontal in direction; it is not bifurcated but ends in a tubercle. The *transverse processes* are of considerable size and their posterior parts are large and prominent. The anterior parts are usually slender, but they may form separate bones, which are then known as *cervical ribs*. The *foramen transversarium* is relatively small; it is sometimes double, or it may be entirely absent.

Particular features.—The tip of the spinous process gives attachment to the lower end of the *ligamentum nuchae*, as well as to a number of muscles. These include the *trapezius*, *rhomboideus minor*, *serratus posterior superior*, *splenius cervicis*, *semispinalis thoracis*, *spinalis cervicis*, *interspinales* and *multifidus*. The *foramen transversarium* is traversed by an accessory vertebral vein or veins: it is traversed by the vertebral artery only on very rare occasions. The *costotransverse bar* of the *transverse*

process, which shows a shallow groove for the ventral ramus of C.7, is often partly deficient. The prominent posterior tubercle gives origin to the scalenus minimus, when it is present and to the aponeurotic layer of fascia which covers the cervical dome of the pleura [suprapleural membrane]. Its lower border gives origin to the highest of the levatores costarum muscles.

FIG. 256.—The cervical vertebræ. Anterior aspect.



THE THORACIC VERTEBRÆ

The **thoracic vertebræ** (figs. 248, 257, 258), twelve in number, show a gradual increase in size from above downwards. All are distinguished by the presence of facets on the sides of the bodies, and all but the last two (sometimes three) by facets on the transverse processes; the former articulate with the heads of the ribs and the latter with the tubercles of the ribs.

The first, ninth, tenth, eleventh and twelfth thoracic vertebræ present certain peculiarities and must be considered separately. The others, although showing individual differences of a minor degree, conform to a common type.

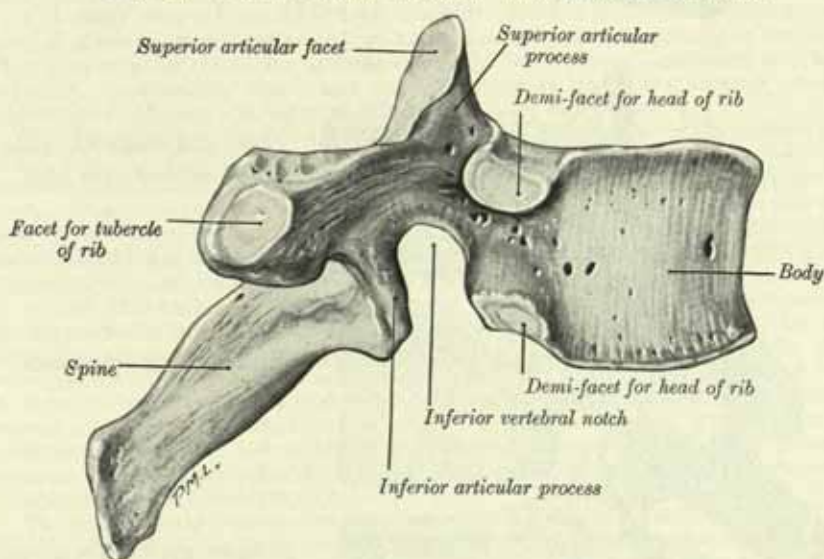
General features.—The *body* of a **typical thoracic vertebra** (fig. 248) resembles in shape a conventional heart from a playing-card, and its anteroposterior and transverse measurements are nearly equal. On each side it bears two *costal facets*; the superior facets are usually the larger and are placed on the upper border near the root of the pedicle; the inferior are situated on the lower border of the body just in front of the inferior vertebral notch. The *vertebral foramen* is relatively small, and its circular outline may be associated with the fact that the *pedicles* show no lateral deviation as they pass backwards from the body. This accounts also for the shortness of the *laminae*, which are broad and thick and overlap each other from above. The *spinous process* is long and is directed downwards and backwards. The *superior articular processes* are thin plates of bone which project upwards at the junction of the laminae and pedicles; their articular facets are almost

flat and are directed backwards and a little laterally and upwards. The *inferior articular processes* are fused to the lateral ends of the laminae; their articular facets are directed forwards and slightly downwards and medially. The *transverse process* is a substantial, club-shaped projection which springs from the vertebral arch at the junction of the lamina and pedicle. It is directed laterally and backwards and bears on its anterior aspect, near its extremity, a facet for articulation with the tubercle of the numerically corresponding rib.

The **first thoracic vertebra** is distinguished by the character of the upper facets on the sides of the body, which are circular in outline, as each articulates with the whole of the head of the first rib. The lower facets are small and semilunar in shape. The spine is thick, long and horizontal; it can be identified easily in the living subject, for it forms a visible projection below the spine of the vertebra prominens.

The **ninth thoracic vertebra** may possess all the features of a typical thoracic vertebra, but it often fails to articulate with the head of the tenth rib, and the lower facets on the body are then absent (fig. 258).

FIG. 257.—A typical thoracic vertebra. Viewed from the right side.



The **tenth thoracic vertebra** articulates with the head of the tenth rib only. The facet is placed at the upper border of the body and encroaches on the pedicle; it is usually incomplete but, when the tenth rib fails to articulate with the ninth thoracic vertebra and does not make contact with the corresponding intervertebral disc, it is complete and circular in outline. The transverse process may, or may not, bear an articular facet for the tubercle of the tenth rib.

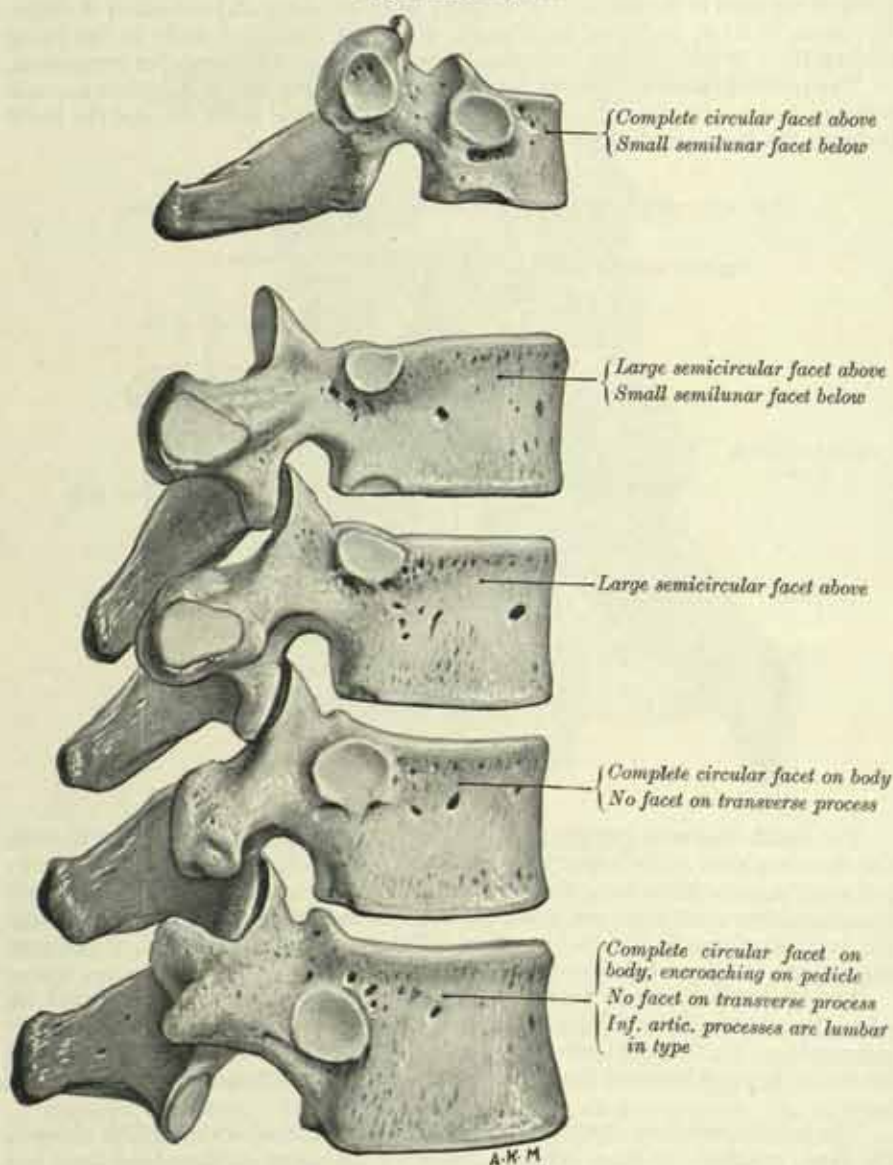
The **eleventh thoracic vertebra** articulates with the head of the eleventh rib only. The circular facet is placed close to the upper border of the body and extends backwards on to the lateral aspect of the pedicle. The transverse process is small but can be gripped between the finger and thumb; it is not marked by an articular facet.

The **twelfth thoracic vertebra** articulates with the head of the twelfth rib only. The facet, roughly circular in outline, lies below the upper border of the body and extends on to the lateral aspect of the pedicle. The body is large and approximates closely to the lumbar type. The transverse process is small and insignificant and is not marked by an articular facet; it presents superior, lateral and inferior tubercles. The inferior articular processes are turned laterally and the articular facets are convex from side to side, like those of a lumbar vertebra.

Particular features of the thoracic vertebræ.—The bodies of the upper thoracic vertebræ show a gradual transition from the cervical to the thoracic type, while the bodies of the lower thoracic vertebræ show a similar transition from the thoracic to the lumbar type. The body of T. 1 is cervical in form, and its transverse is nearly

twice as great as its antero-posterior measurement. The body of T. 2 retains the cervical type, but its breadth is less and the disproportion between its two measurements is diminished. The body of T. 3 is actually the smallest of the thoracic bodies, but its anterior aspect, instead of being flattened like the bodies of T. 1 and T. 2, is rounded off and is convex forwards from side to side. From this point the bodies gradually increase in size and, owing to an increase in the antero-posterior measurement, that of T. 4 is typically heart-shaped. The bodies of T. 5 to T. 8 show a

FIG. 258.—The first, ninth, tenth, eleventh and twelfth thoracic vertebrae. Right lateral aspects.



gradual increase in the anteroposterior measurement while the transverse measurement shows little alteration. These four vertebrae, when seen on transverse section, are asymmetrical, for the left side of each body shows a flattening produced by the pressure of the thoracic aorta. The remaining vertebrae increase in size more rapidly, the increase affecting all the measurements of the body, so that T. 12 approximately closely to the shape of a typical lumbar vertebra.

The upper and lower borders of the bodies in front and behind give attachment to the anterior and posterior longitudinal ligaments, respectively; and the margins of the costal facets give attachment to the capsular and radiate ligaments of the joints of

the heads of the ribs. The longus cervicis muscle arises from the bodies of the first three thoracic vertebrae, lateral to the anterior longitudinal ligament. The psoas major and minor muscles arise from the lateral aspect of the twelfth thoracic vertebra near its lower border.

The *pedicles* increase in thickness from above downwards. The *superior vertebral notch* is scarcely recognisable except in the first thoracic vertebra, but the *inferior notch* is deep and conspicuous. The upper borders of the *laminae* and the lower parts of their anterior surfaces serve for the attachment of the ligamenta flava; their dorsal aspects give insertion to the rotatores muscles.

The *transverse processes* gradually diminish in length from above downwards. In the upper six (sometimes five) the costal facets are concave and face forwards and laterally; in the others the facets are flattened and face upwards, laterally, and slightly forwards. The tuberculated extremity of the process gives attachment to the lateral costotransverse ligament: its lower border, to the superior costotransverse ligament: its anterior surface, medial to the facet, to the inferior costotransverse ligament: and its base to the posterior costotransverse ligament. In addition, the upper and lower borders of the transverse process provide attachment for intertransverse muscles or their fibrous vestiges, and the posterior surface for the deep muscles of the back—the levator costarum arising from the dorsal aspect of the tuberculated extremity under cover of the longer muscles.

The *spines* overlap from the fifth to the eighth, which is the longest and most nearly vertical of the thoracic spines. Above and below they are less oblique in direction.* They give attachment to the supraspinous and interspinous ligaments, and to the trapezius, rhomboideus major and minor, latissimus dorsi, the serratus posterior superior and inferior, and many of the deep muscles of the back.

The **first thoracic vertebra** resembles a cervical vertebra in the shape of its body. In addition, the posterolateral parts of its upper border are raised, as they are in the cervical region, and this projection forms the anterior border of the superior vertebral notch, which is a distinctive feature of this vertebra. The upper facet on the side of the body is not always complete, as the head of the first rib often articulates with the intervertebral disc between the seventh cervical and the first thoracic vertebra. Immediately below the facet there is frequently a small, deep depression in the bone.

In the **eleventh and twelfth thoracic vertebrae** the spinous processes are characteristically triangular, with blunted apices. In each case, the lower border is horizontal, or nearly so, and the upper border is oblique. In the region of the transverse process of the twelfth thoracic vertebra three little tubercles can be distinguished. Of these the *superior* is the largest and juts upwards. It corresponds to the mamillary process of a lumbar vertebra, but it is not so closely connected with the superior articular process. The *lateral tubercle* is small and corresponds to the true transverse process. The *inferior tubercle*, directed downwards, corresponds to the accessory process of a lumbar vertebra.

In distinguishing between these two vertebrae the student should be guided by (1) the character of the inferior articular processes which, in a twelfth, are lumbar in type and are slightly convex, facing laterally and forwards; (2) the size and character of the transverse process; and (3) the distance between the costal facet and the upper border of the vertebra (p. 237).

THE LUMBAR VERTEBRÆ [VERTEBRÆ LUMBALES]

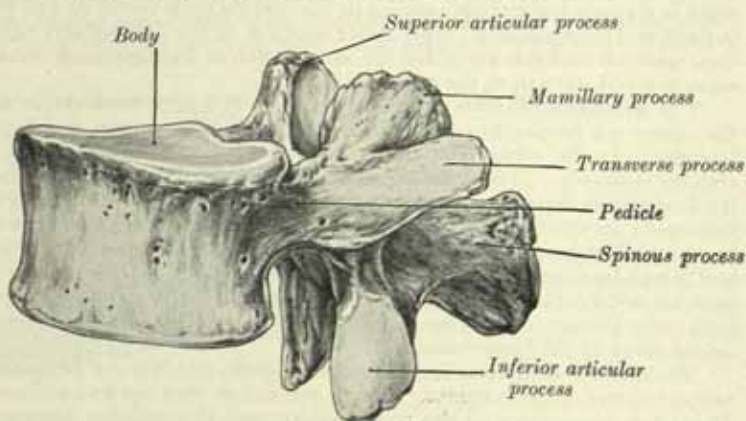
General features.—The **lumbar vertebrae** (figs. 259–261), five in number, can be distinguished from the other vertebrae by their great size and by the absence of costal facets on the sides of the bodies.

The *body* is large, wider from side to side than from before backwards, and a little deeper in front than behind. The *vertebral foramen* is triangular in shape, larger than in the thoracic region but smaller than in the cervical region. The shape is accounted for by the shortness of the pedicles and the direction of the laminae, which pass backwards and medially. The *spinous process* projects almost horizontally backwards, is quadrangular, and is thickened along its posterior and inferior borders. The *superior articular processes* bear articular facets which face medially and backwards and are gently concave. The posterior border of each process is marked by a rough elevation, termed the *mamillary process*. The *inferior articular processes* bear articular facets which are slightly convex and face laterally and

* In quadrupeds the majority of the spines of the thoracic vertebrae project dorsally and caudally, while those in the lumbar region are directed dorsally and headwards. The change in inclination is effected in one of the lower thoracic vertebrae, the spine of which points almost straight dorsally. This vertebra is known as the *anticlinal*, and in man its representative is the eleventh thoracic.

forwards. The *transverse processes* are thin and elongated, with the exception of those of the fifth lumbar vertebra, which are strong and substantial. A small, rough

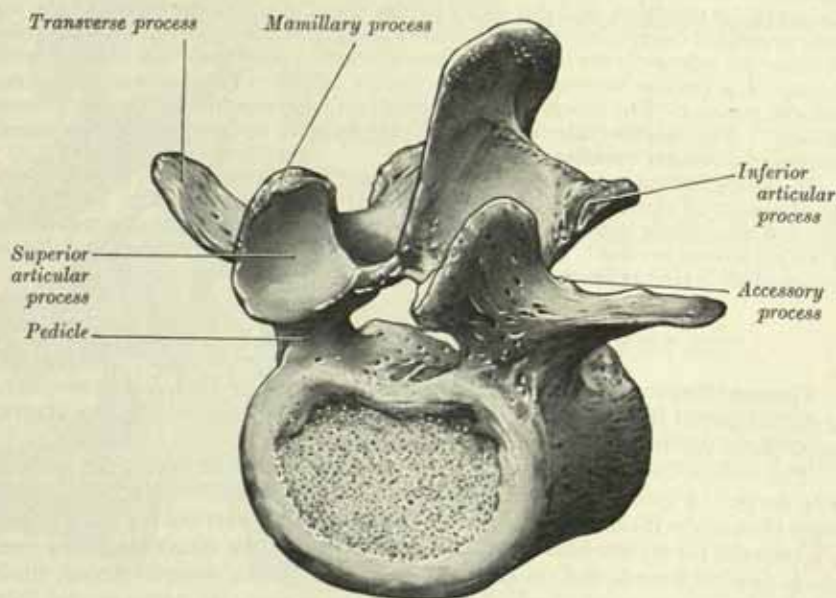
FIG. 259.—A lumbar vertebra. Left lateral aspect.



elevation marks the postero-inferior aspect of the root of each transverse process and is termed the *accessory process*.

The **fifth lumbar vertebra** (fig. 261) can be distinguished by the fact that its *transverse process* is strong and massive and is connected to the *whole of the lateral surface of the pedicle and encroaches on the side of the body*. In addition, its body is

FIG. 260.—A lumbar vertebra. Posterosuperior aspect, viewed obliquely from the left side.

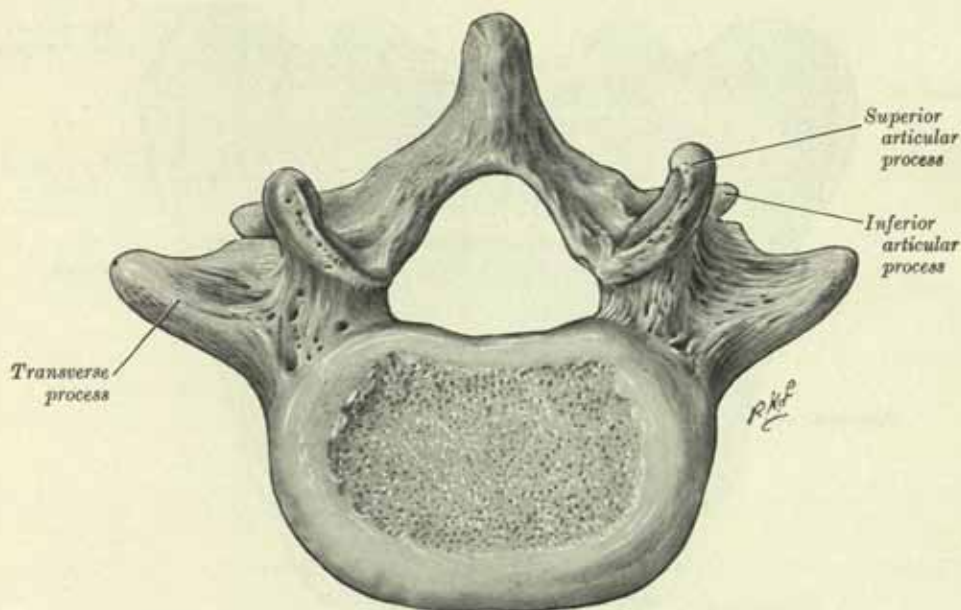


the largest of all the lumbar vertebrae and it is usually deeper in front than behind, a condition which is associated with the prominence of the sacrovertebral angle.

Particular features.—The upper and lower borders of the *bodies* in front and behind give attachment to the anterior and posterior longitudinal ligaments. Lateral to the anterior longitudinal ligament, the bodies of the upper lumbar vertebrae (three on the right side; two on the left) give origin to the crura of the diaphragm. Behind the line of the crus the psoas major arises from the bodies of all the lumbar vertebrae.

This muscle throws tendinous arches across the sides of the bodies to protect the lumbar vessels. The *vertebral foramen* of the first lumbar vertebra contains the lower part of the spinal cord—the *conus medullaris*; the lower foramina contain the *cauda equina* and the spinal meninges. The *pedicle* is strong, and springs from the posterolateral aspect of the body just below its upper border. The *superior vertebral notch*, though shallow, is easily recognisable: the *inferior notch* is of considerable depth. The *laminae* are broad, short and strong, but they do not overlap one another to the same extent as they do in the thoracic region. They give attachment to the *ligamenta flava*. The *spinous processes* provide attachment for the posterior lamella of the lumbar fascia, the *sacrospinalis*, the *spinalis thoracic*, the *multifidus*, the *interspinal muscles* and *ligaments* and the *supraspinous ligaments*. The spinous processes of the fifth lumbar vertebra is the least substantial and its extremity is more or less rounded and down-turned. The *superior articular processes* are wider apart than the *inferior* in the upper lumbar region, but the difference is very slight in the fourth, and in the fifth the two measurements are approximately equal. The articular facets are so shaped that, while they permit of flexion and extension, they prevent rotation of the lumbar

FIG. 261.—The fifth lumbar vertebra. Superior aspect.



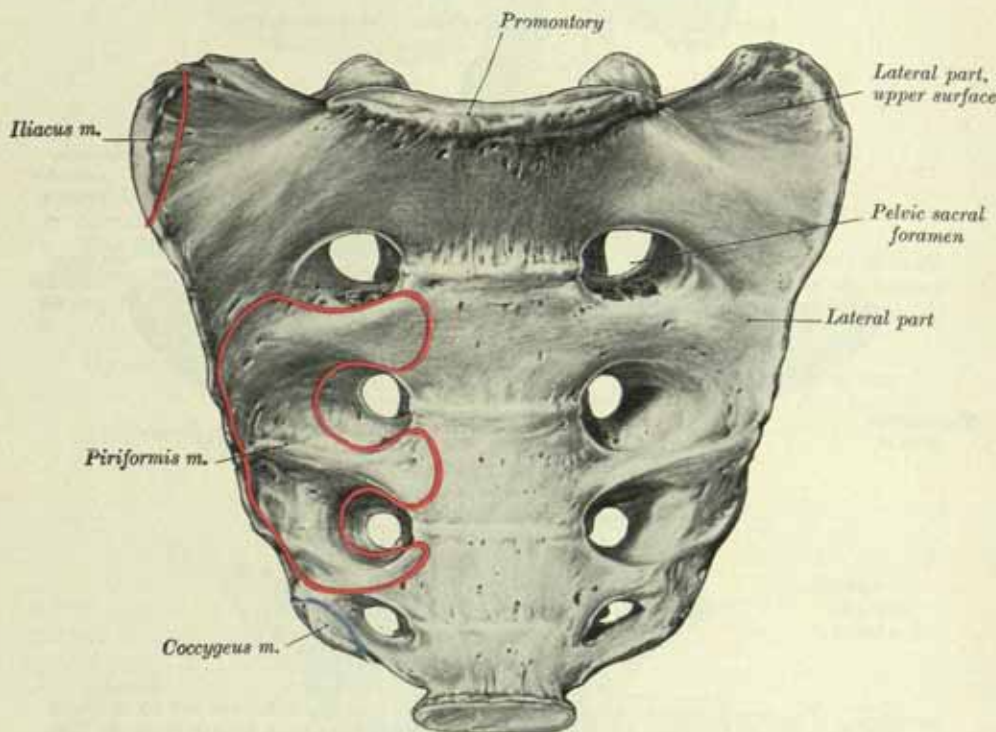
vertebræ. The *transverse processes*, with the exception of the fifth, are not so strongly built as the other parts of the lumbar vertebrae. They increase in length from the first to the third—which is the longest of all the transverse processes—and then become shorter. The fifth inclines *upwards*, as it passes laterally and slightly backwards. A faint, vertical ridge marks the anterior surface of the transverse process nearer the tip than the root. It gives attachment to the anterior layer of the lumbar fascia and separates the surface into a medial area for the attachment of the *psaos major* and a lateral area for the *quadratus lumborum*. The tip of the process gives attachment to the middle layer of the lumbar fascia, but, in addition, the tip of the first gives attachment to the medial and lateral arcuate ligaments and the tip of the fifth to the *ilio-lumbar ligament*. The posterior surfaces of the transverse processes are covered by the deep muscles of the back and give origin to fibres of the *longissimus thoracis* muscle. The upper and lower borders of the process give attachment to lateral intertransverse muscles. The *mamillary process* is homologous with the superior tubercle in the twelfth thoracic vertebra. It gives attachment to the *multifidus* and to the medial intertransverse muscle. The *accessory process** varies in prominence and may be difficult to identify. It gives attachment to the medial intertransverse muscle. The *costal element* is incorporated in the transverse process (fig. 115).

* The mamillary and accessory processes "are merely muscular processes which, represented and conjoined in the thoracic region, become separated in the lumbar region by the passage of the internal (medial) branch of the posterior division (posterior primary ramus) of the lower thoracic and lumbar nerves between them." (F. Wood Jones, *Journal of Anatomy and Physiology*, 47, 1912).

THE SACRUM [OS SACRUM]

General features.—The **sacrum** (figs. 262–266) is a large bone, triangular in shape, formed by the fusion of the five sacral vertebrae. It is situated at the upper and posterior part of the pelvic cavity, where it is inserted like a wedge between the two hip-bones. Its narrow, blunted *apex* is at the inferior end of the bone and articulates with the coccyx. At the opposite end the wide *base* articulates with the fifth lumbar vertebra, with which it forms the *sacrovertebral angle*. The bone is placed very obliquely and is curved longitudinally so that its dorsal surface is convex and its pelvic surface is concave (fig. 264). This ventral concavity serves to increase the capacity of the true pelvis. In addition to a base and an apex the sacrum possesses *dorsal*, *pelvic*, and *lateral surfaces* and encloses a bony canal.

FIG. 262.—The sacrum. Pelvic surface.



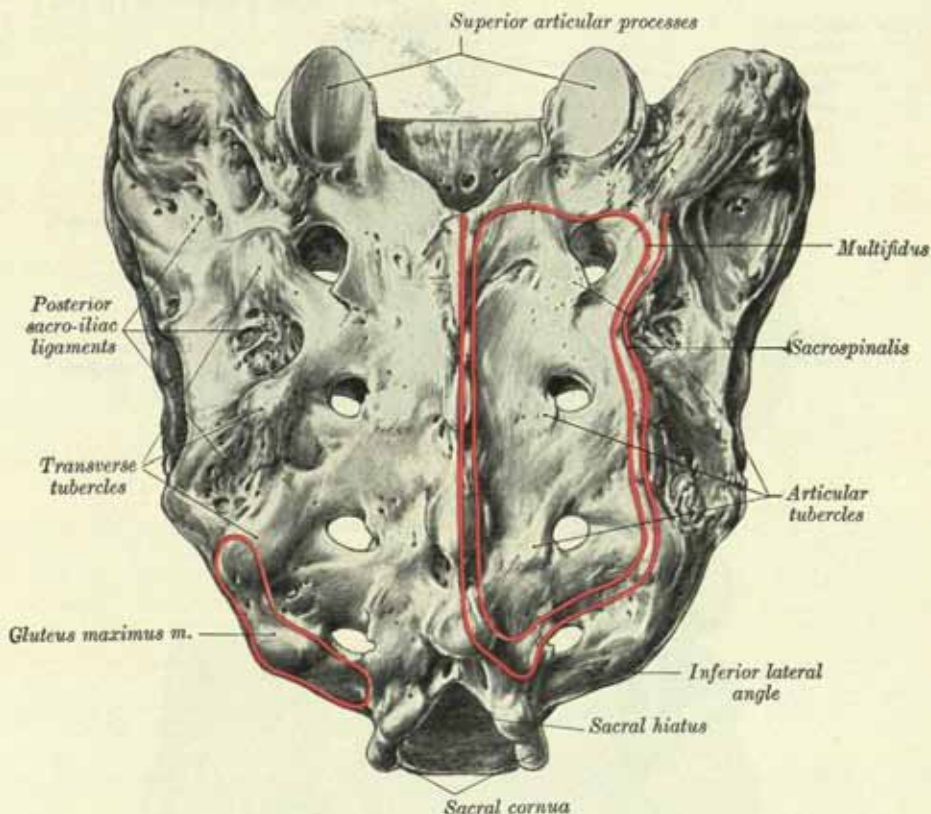
In the child the individual sacral vertebrae are connected by cartilage and can be separated by maceration. The adult bone shows many signs of its vertebral constitution, especially on its basal aspect.

The **base** (fig. 265) is formed by the upper surface of the *first sacral vertebra* and presents all the features of a typical vertebra in a slightly modified form. The *body* is large and much wider from side to side than from before backwards. Its anterior projecting edge is named the *sacral promontory*. The vertebral foramen is triangular, and its shape is explained by the fact that the *pedicles* are short, widely separated, and are directed backwards and laterally. The *laminae* are very oblique and incline downwards, medially and backwards. Where they meet, the *spinous process* is represented by a spinous tubercle. The *superior articular processes* project upwards and bear concave articular facets which face medially and backwards to articulate with the inferior articular processes of the fifth lumbar vertebra. The posterior part of each process projects backwards, and its lateral aspect bears a roughened area which corresponds to the mamillary process of a lumbar vertebra. The region of the *transverse process* shows important modifications. A broad, sloping mass of bone projects from the lateral side of the body, pedicle and superior articular process (fig. 265)—a feature which is not found in any of the other vertebrae, although it is

foreshadowed in the fifth lumbar vertebra. It is formed by the transverse process and the costal element fused to each other and to the rest of the vertebra, and forms the upper surface of the *lateral part* of the sacrum.

The **pelvic surface** of the sacrum is concave and is directed downwards and forwards. It is marked by four pairs of *pelvic sacral foramina*, which communicate through the intervertebral foramina with the sacral canal. They transmit the ventral rami of the first four sacral nerves. The large area which lies between the foramina of the right and left sides is formed by the flattened pelvic surfaces of the bodies of the sacral vertebrae, and the lines of fusion of contiguous vertebrae are clearly visible as four raised *transverse ridges*. The bars of bone which separate the foramina from one another on each side represent the *costal elements*, which are fused to the vertebrae. Lateral to the foramina the costal elements unite with one

FIG. 263.—The sacrum. Dorsal surface.



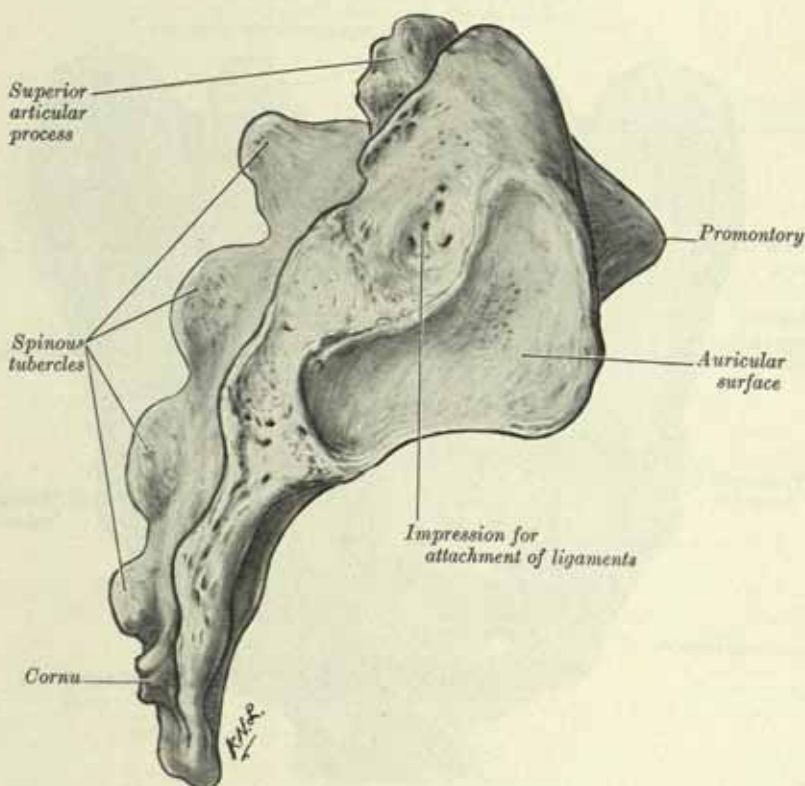
another and, posteriorly, they unite with the transverse processes to form the *lateral part* of the sacrum.

The **dorsal surface** (fig. 263) is convex and is directed backwards and upwards. It is marked in the median plane by a raised crest, which bears four (sometimes only three) *spinous tubercles*. These represent the fused spines of the sacral vertebrae. Below the fourth spinous tubercle there is a \cap -shaped gap in the posterior wall of the sacral canal, termed the *sacral hiatus*. This gap is produced by the failure of the laminae of the fifth sacral vertebra to meet in the median plane, and, as a result, the posterior surface of the body of that vertebra is exposed on the dorsal surface of the sacrum. Lateral to the median crest, the posterior surface is formed by the fused *laminae*. Lateral to this area the dorsal surface of the sacrum presents on each side four *dorsal sacral foramina*. Like the pelvic foramina they communicate with the sacral canal through the intervertebral foramina; and each transmits the dorsal (posterior primary) ramus of a sacral nerve. Medial to the foramina, and in line with the superior articular process of the first sacral vertebra, the bone is marked on each side by a row of four small tubercles, which represent contiguous articular processes

fused together. The inferior articular processes of the fifth sacral vertebra are free and project downwards at the sides of the sacral hiatus. They are termed the *sacral cornua* and are connected to the cornua of the coccyx by ligaments, termed the intercornual ligaments. The roughened area to the lateral side of the dorsal sacral foramina is formed by the fused transverse processes and presents a row of *transverse tubercles*.

The **lateral surface** (fig. 264) of the sacrum is formed by the fused transverse processes and costal elements. It is wide above but rapidly diminishes in breadth in its lower part. The broad, upper part bears an ear-shaped surface, termed the *auricular surface*, for articulation with the ilium, and the area behind it is rough and deeply pitted for the attachment of ligaments. In order to ensure the stability of the

FIG. 264.—The sacrum. Right lateral aspect.



body in the erect posture, the sacro-iliac joint, through which one half of the weight of the trunk is transmitted to each lower limb, must provide a good bearing surface. This is obtained by the fusion of the sacral vertebrae and by the persistence of substantial portions of the costal elements. The auricular surface is borne by the costal elements and is shaped like the inverted letter L. The cephalic limb is the shorter and is restricted to the first sacral vertebra: the caudal limb extends downwards to the lower limit of the second or to the middle of the third sacral vertebra. The lower part of the lateral surface takes no part in the transmission of the weight of the body and is consequently reduced in breadth. At its lower end it bends or curves medially to reach the side of the body of the fifth sacral vertebra. The point at which the change of direction occurs is termed the *inferior lateral angle*. Below the angle the lateral surface forms a thin border.

The **apex** of the sacrum is formed by the inferior surface of the body of the fifth sacral vertebra and bears an oval facet for articulation with the coccyx.

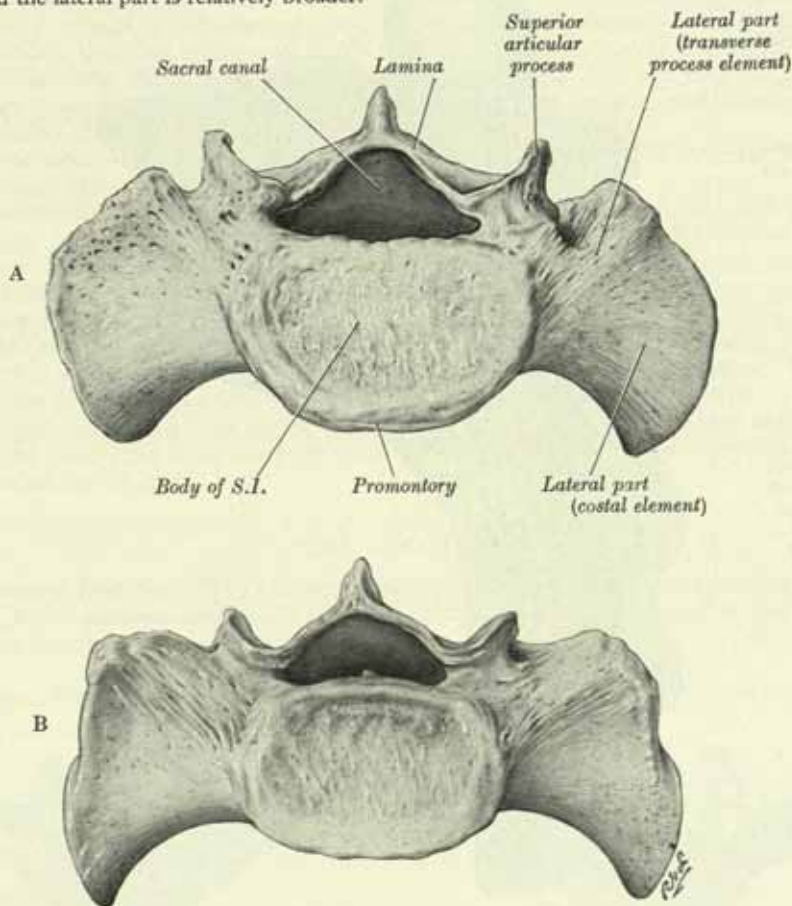
The **sacral canal** (fig. 266) is formed by the vertebral foramina of the sacral vertebrae and is triangular on transverse section. Its upper opening, seen on the basal surface, appears to be set obliquely but, owing to the inclination of the sacrum,

it is directed upwards in the living subject. The lateral wall of the canal presents four intervertebral foramina (fig. 266), through which the canal is connected with both the pelvic and the dorsal sacral foramina. The lower opening is the *sacral hiatus*.

Particular features.—The ventral and dorsal parts of the *body of the first sacral vertebra* give attachment to the lowest fibres of the anterior and posterior longitudinal ligaments respectively. The upper borders of the *laminae* of the first sacral vertebra give attachment to the lowest pair of ligamenta flava. The *upper surface of the lateral part* is smooth and slightly concave in its medial part but is irregularly roughened in its lateral part. It is covered almost entirely by the *psoas major*

FIG. 265.—The base of the sacrum in the male (A) and in the female (B).

Note that the body of S.I. forms a larger portion of the total breadth of the base in the male than it does in the female. In the latter the body is relatively smaller and the lateral part is relatively broader.



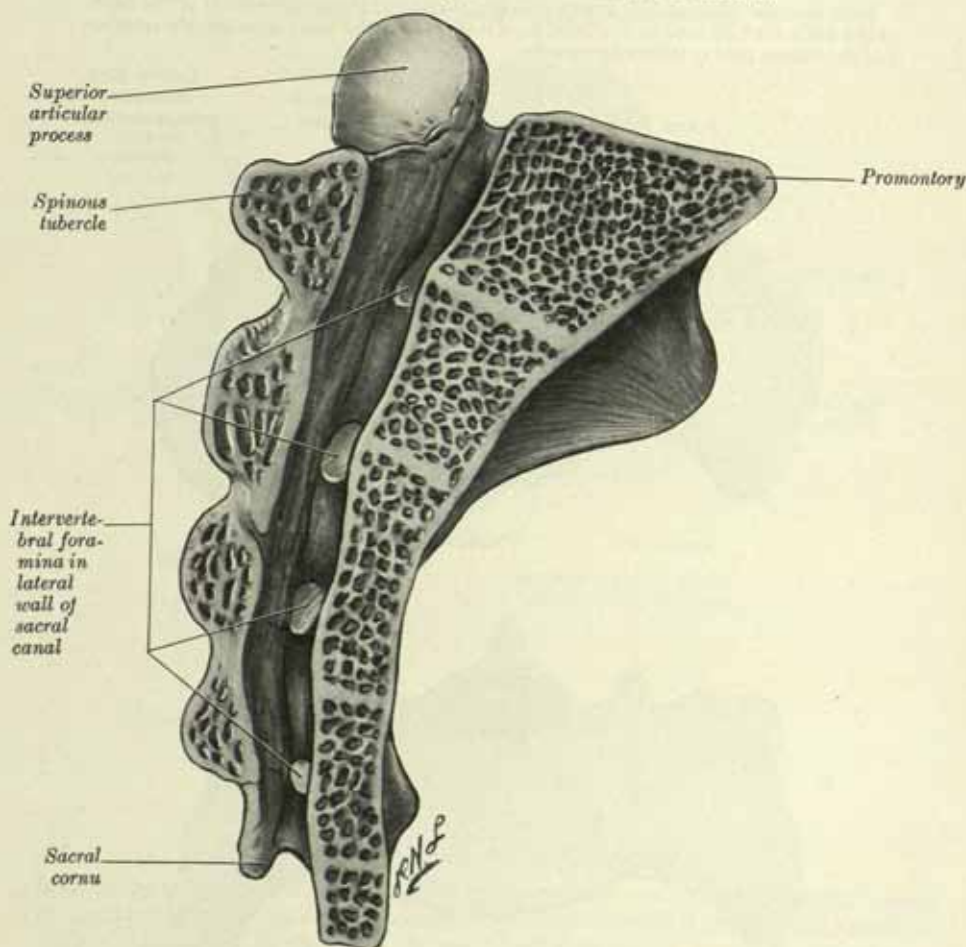
muscle. The smooth area is marked by an oblique, shallow groove which lodges the lumbosacral trunk. The rough area gives attachment to the lower band of the ilio-lumbar ligament (p. 506) (often termed *lumbosacral ligament*), which lies on the lateral side of the fifth lumbar nerve, and to the ventral ligament of the sacro-iliac joint. The anterolateral part of the area gives origin to a portion of the iliacus muscle (fig. 262).

The *pelvic surface* of the sacrum gives origin on each side to the piriformis muscle (fig. 262). On emerging from the pelvic sacral foramina the ventral rami of the first three sacral nerves pass at once on to the anterior surface of the muscle. Along the medial margins of the foramina, on each side, the sympathetic trunk descends in contact with the bone, and in the median plane the median sacral vessels form an intimate relation. Lateral to the foramina the lateral sacral vessels bear a variable relation to the bone. The ventral surfaces of the bodies of the first and second and part of the third sacral vertebra are covered with parietal peritoneum and

crossed obliquely, to the left of the median plane, by the root of the pelvic mesocolon. The rectum lies in contact with the pelvic surfaces of the bodies of the third, fourth and fifth sacral vertebrae, but the bifurcation of the superior rectal artery into right and left branches intervenes between it and the third sacral vertebra.

The *dorsal surface* of the sacrum is rough and irregular. The sacrospinalis arises by an elongated U-shaped origin from the spinous and transverse tubercles, and covers the multifidus, which arises from the intervening area (fig. 263). The dorsal (posterior primary) rami of the upper three sacral nerves pierce these muscles after they emerge from the dorsal sacral foramina. It not infrequently happens that the laminae of the fourth sacral vertebra fail to meet in the median plane behind. The sacral hiatus is then elongated considerably.

FIG. 266.—A median sagittal section through the sacrum.



The *auricular surface* is covered with hyaline cartilage in the recent state and is formed entirely by the costal elements. The rough area behind it shows two well-marked depressions and gives attachment to the strong interosseous sacro-iliac ligaments. Below the auricular surface the lateral aspect of the sacrum gives attachment to the gluteus maximus, the sacrotuberous and sacrospinous ligaments and the coccygeus muscle, the structures being enumerated from behind forwards.

The *sacral canal* contains the cauda equina (including the filum terminale) and the spinal meninges. Opposite the middle of the sacrum the subarachnoid and subdural spaces become closed, and the lower sacral nerve roots and the filum terminale pierce the arachnoid and dura mater at that level. The filum terminale emerges below at the sacral hiatus and passes downwards across the dorsal surface of the fifth sacral vertebra and the sacrococcygeal joint to reach the coccyx. The fifth sacral nerve also emerges through the sacral hiatus close to the medial side of the sacral cornu and grooves the lateral part of the body of the fifth sacral vertebra.

Differences in the sacrum of the male and female.—In the female the sacrum is shorter and wider than in the male, reflecting the necessity for a wider and a shallower pelvic cavity. The upper part of the bone is flattened, and the lower part curved abruptly forwards, whereas in the male the curvature is more evenly distributed over the whole length of the bone. It should be remembered, however, that the curvature of the bone may vary considerably in different specimens of the same sex. In the female the pelvic surface of the bone faces downwards more than in the male; this increases the size of the pelvic cavity and renders the sacro-vertebral angle more prominent. In the female the auricular surface for articulation with the ilium is shorter than that in the male, extending along the sides of the first and second sacral vertebrae only; in the male it is continued down to the middle or lower limit of the third vertebra. Owing to the great size of the body of the fifth lumbar vertebra, the upper surface of the body of the first sacral vertebra occupies a larger proportion of the base of the sacrum in the male than it does in the female (fig. 265). No difficulty will be experienced in distinguishing a typical male or a typical female sacrum, but, as the sexual characters are not always pronounced, there are many cases in which it is by no means easy to determine the sex. When any difficulty is experienced in determining the sex of a sacrum, greatest stress should always be laid on the relationship between the length and the breadth of the bone.

Structure.—The sacrum consists of spongy substance enveloped by a thin layer of compact bone.

Variations.—Either the fifth lumbar vertebra or, more commonly, the first coccygeal vertebra may become incorporated in the sacrum, which then has six vertebrae. The inclusion of the fifth lumbar vertebra is usually incomplete and it may be limited to one or other side. In the most minor degree of the abnormality the transverse process of the fifth lumbar vertebra is unusually large, and articulates with the sacrum at the dorsolateral part of the upper surface of its lateral part. Reduction of the number of the constituents of the sacrum is less common. The transverse process of the first sacral segment may not be joined to the rest of the lateral part on one or both sides, and a considerable part of the dorsal wall of the sacral canal may be wanting, in consequence of the imperfect development of the laminae and spines.

THE COCCYX

General features.—The **coccyx** (figs. 267, 268) is a small bone, triangular in shape, which consists usually of four rudimentary vertebrae fused together, but the number may be increased to five or reduced to three. Not infrequently, the first

FIG. 267.—The coccyx. Pelvic aspect.

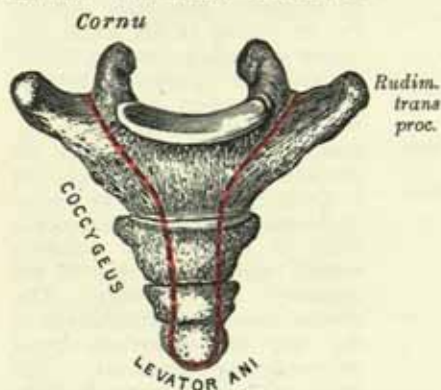
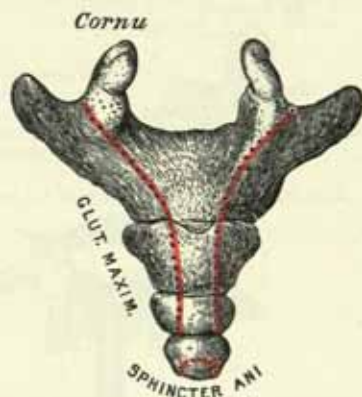


FIG. 268.—The coccyx. Dorsal aspect.



coccygeal vertebra exists as a separate piece. The bone is directed downwards and ventrally from the apex of the sacrum, so that its pelvic surface faces upwards and forwards and its dorsal surface downwards and backwards.

The *base* of the coccyx, formed by the upper surface of the body of the *first coccygeal vertebra*, presents an oval, articular facet for articulation with the apex of

the sacrum. Dorsilateral to the facet, two processes, named the *coccygeal cornua*, project upwards to articulate with the sacral cornua; they are the homologues of the pedicles and superior articular processes of the movable vertebrae. A rudimentary *transverse process* projects laterally and slightly upwards from each side of the body of the first coccygeal vertebra and may ascend to articulate or fuse with the inferior lateral angle of the sacrum. In that event five pairs of foramina are found in the sacrum.

FIG. 269.—The ossification of a typical vertebra.

By 3 primary centres

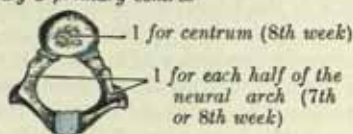


FIG. 270.

By 3 secondary centres

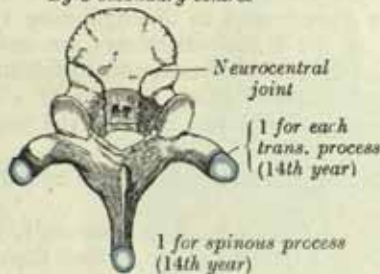


FIG. 271.

By 2 annular discs

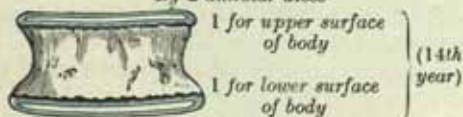


FIG. 272.—The ossification of the atlas.

By 3 centres

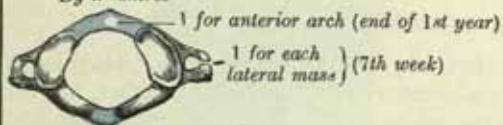
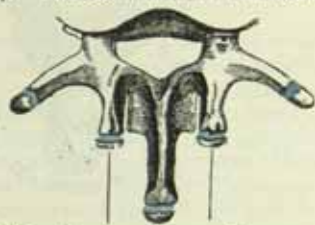


FIG. 273.—The ossification of the axis.

By 7 centres



FIG. 274.—The ossification of a lumbar vertebra.



2 additional centres for mamillary processes

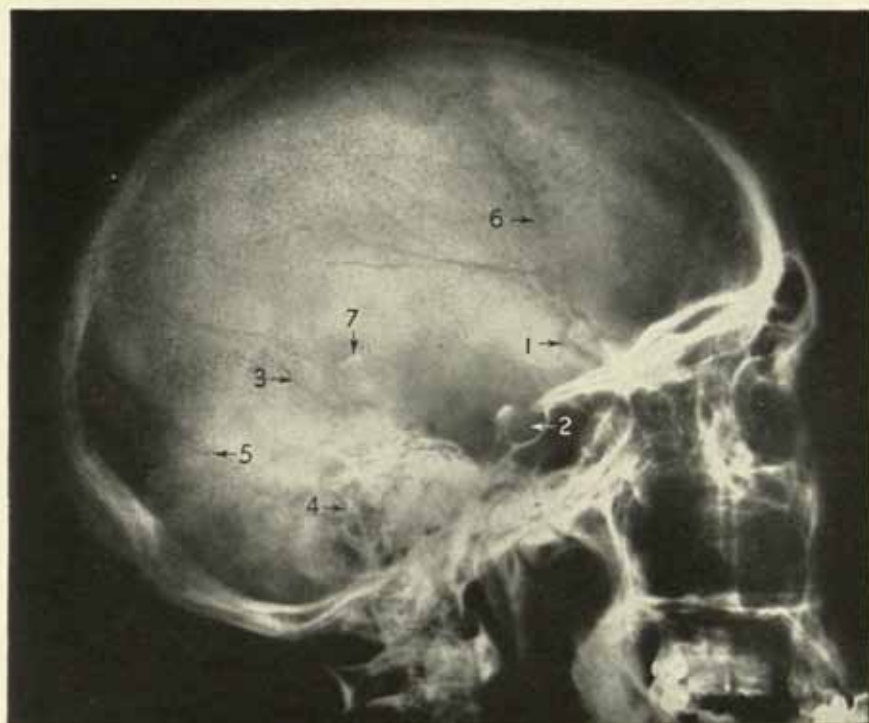
The *second, third and fourth coccygeal vertebrae* diminish successively in size and are usually fused with one another. They are mere nodules of bone, which represent the rudimentary bodies of the vertebrae, although the second may show traces of transverse processes and pedicles.

Particular features.—The lateral parts of the *pelvic surface*, including the rudimentary transverse process, give insertion to the levatores ani and the coccygei. The ventral sacrococcygeal ligament is attached to the front of the body of the first, and may extend downwards to reach the second coccygeal vertebra (fig. 521). The *cornua* give attachment to the intercornual ligaments. The interval between the body of the fifth sacral vertebra and the articulating sacral and coccygeal cornua on each side represents the intervertebral foramen between the fifth sacral and the first coccygeal vertebra, and transmits the fifth sacral nerve. The dorsal ramus of that nerve descends behind the rudimentary *transverse process*, but its ventral ramus passes forwards through a foramen placed between the transverse process and the sacrum and bounded laterally by the lateral sacrococcygeal ligament, which connects the process to the inferior lateral angle of the sacrum. The *dorsal surface* of the coccyx gives origin, on each side, to the gluteus maximus muscle and, at its tip, to the sphincter ani externus. The median area gives attachment to the deep and superficial dorsal sacrococcygeal ligaments. The latter extends downwards from the margins of the sacral hiatus and may close the lower end of the sacral canal. The filum termin-

ale, which is situated between the two ligaments, blends with them on the dorsal surface of the first coccygeal vertebra.

The ossification of the vertebral column.—Each typical vertebra is ossified from three primary centres (fig. 269), two for the vertebral arch, and one for

PLATE III



Lateral radiograph of the skull in an adult.

1. Groove for the anterior branches of the middle meningeal vessels. 2. Hypophyseal fossa. 3. Groove for the posterior branches of the middle meningeal vessels. 4. Mastoid air-cells. 5. Lambdoid suture. 6. Coronal suture. 7. Calcareous deposits in the pineal body.

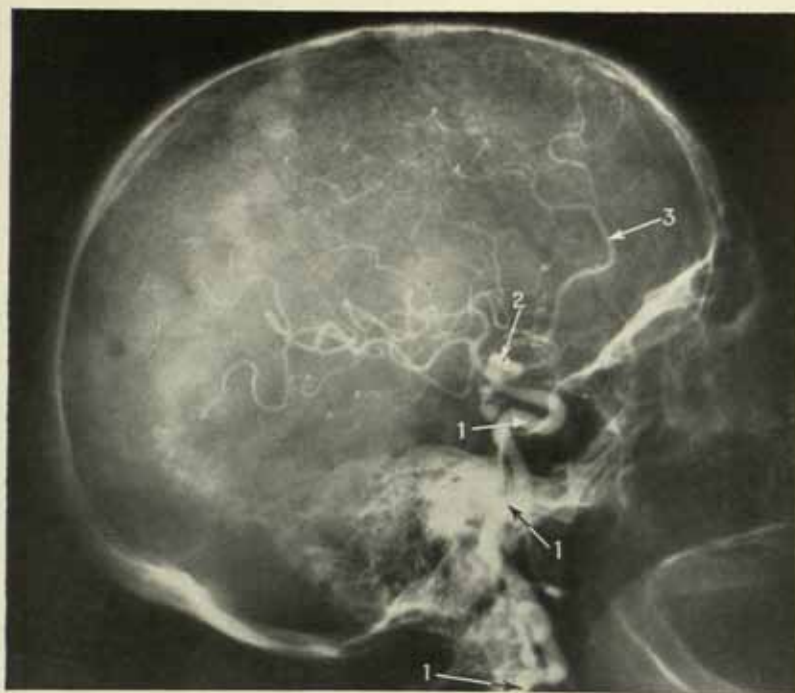


FIG. 1.—Arteriogram of the intracranial course and branches of the right internal carotid artery.

1. Right internal carotid artery in the upper part of the neck: in the carotid canal of the petrous part of the temporal bone: and in the cavernous sinus. Note the sharp loop which the artery makes as it emerges from the sinus. 2. Middle cerebral artery, foreshortened as it lies in the stem of the lateral sulcus. 3. Anterior cerebral artery, curving round the genu of the corpus callosum.

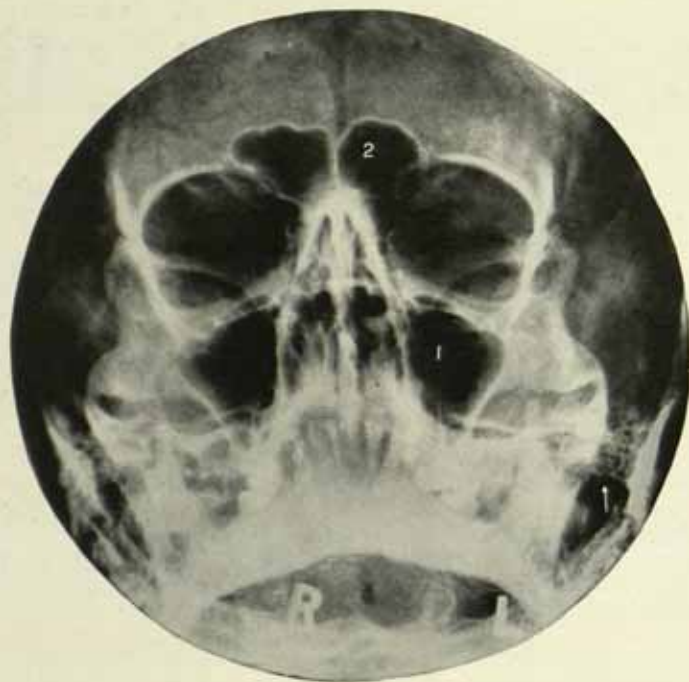


FIG. 2.—Radiograph of adult skull. Frontal view. 1 = maxillary sinus; 2 = frontal sinus. The arrow is directed towards the mastoid air-cells.

the body.* Ossification of the vertebral arches begins in the upper cervical vertebrae about the seventh or eighth week of intrauterine life, and gradually extends down the column. The centres first appear in the situations where the transverse processes afterwards project, and spread backwards to the laminae, forwards into the pedicles and laterally into the transverse processes. Ossification of the bodies begins in the lower thoracic vertebrae about the eighth week of intrauterine life, and subsequently extends upwards and downwards along the column. The centre for the body constitutes the *centrum*, which does not correspond to the whole of the body of the adult vertebra, for the posterolateral portions of the body are ossified from the centres for the vertebral arch. During the first few years of life the centrum is connected to each half of the vertebral arch by a primary cartilaginous joint, termed the *neurocentral joint*. In the thoracic region the costal facets on the bodies lie behind the neurocentral joints. At birth a vertebra consists of three pieces, viz., the centrum and the halves of the vertebral arch. During the first year the halves of the arch unite behind, union taking place first in the lumbar region and then extending upwards through the thoracic and cervical regions. In the upper cervical vertebrae the centra unite with the arches about the third year, but in the lower lumbar vertebrae union is not completed until the sixth year. Until puberty the upper and under surfaces of the bodies and the ends of the transverse and spinous processes are cartilaginous, but about the fourteenth year five secondary centres appear, one for the tip of each transverse process, one for the end of the spinous process, and two annular epiphysal discs for the circumferential parts of the upper and lower surfaces of the body (figs. 270, 271). The costal articular facets arise as extensions of the annular epiphysal discs (Dixon).† These secondary centres fuse with the rest of the bone about the age of twenty-five years. In the bifid spinous processes of the cervical vertebrae there are two secondary centres.

Exceptions to this mode of ossification occur in the first, second and seventh cervical vertebrae, and in the lumbar vertebrae.

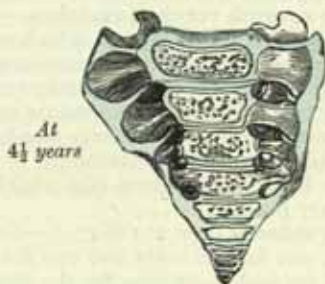
The *atlas* is usually ossified from three centres (fig. 272). One appears in each lateral mass about the seventh week of intrauterine life, and gradually extends into the posterior arch, where the two unite between the third and fourth years, either directly or through the medium of a separate centre. At birth, the anterior arch consists of fibrocartilage; in this a separate centre appears about the end of the first year, and unites with the lateral masses between the sixth and eighth years—the lines of union extending across the anterior portions of the superior articular facets. Occasionally the anterior arch is formed by the forward extension and

FIG. 275.—The ossification of the sacrum and coccyx.



At birth

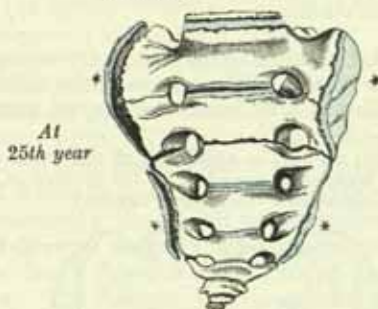
FIG. 276.



At
4½ years

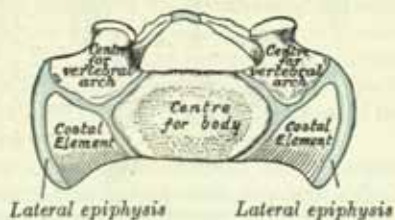
FIG. 277.

The two epiphysal plates for each lateral surface are marked by asterisks.



At
25th year

FIG. 278.—The base of the sacrum of a child.



Lateral epiphysis

Lateral epiphysis

* The body is occasionally ossified from two lateral centres which sometimes fail to unite. The suppression of one of these centres leads to the formation of a wedge-shaped vertebra, and is a well-recognised cause of lateral curvature of the vertebral column. The condition is frequently multiple.

† A. Francis Dixon, *J. Anat.*, 55, 1920.

ultimate union of the centres for the lateral masses; sometimes it is ossified from two laterally placed centres.

The **axis** is ossified from five primary and two secondary centres (fig. 273). The vertebral arch is ossified from two primary centres, and the centrum from one, as in a typical vertebra; the centres for the arch appear about the seventh or eighth week of intrauterine life, the centre for the centrum about the fourth or fifth month. The dens represents the centrum of the atlas, and is ossified almost entirely from two laterally-placed centres; these appear about the sixth month of intrauterine life, and join before birth to form a conical mass, deeply cleft above. A wedge-shaped piece of cartilage fills the cleft and forms the summit of the process: in this cartilage a centre appears about the second year and unites with the main mass of the process about the twelfth year. It is regarded as representing the proatlas.* The base of the process is separated from the body of the axis by a cartilaginous disc, the circumference of which ossifies, but the centre remains cartilaginous until advanced age; in this cartilaginous disc rudiments of the lower epiphysal lamella of the atlas and the upper epiphysal lamella of the axis may sometimes be found. In addition a thin epiphysal plate is formed on the under surface of the body of the bone about the time of puberty.

The seventh cervical vertebra.—The costal processes of this vertebra are usually ossified from separate centres, which appear about the sixth month of intrauterine life, and join the body and transverse processes between the fifth and sixth years. As already stated (p. 235), the costal processes may persist as separate pieces, and grow laterally and forwards, to constitute cervical ribs.

Separate ossific centres have also been found in the costal processes of the fourth, fifth, and sixth cervical vertebrae.

The lumbar vertebrae (fig. 274) have each two additional centres, one for each mamillary process.

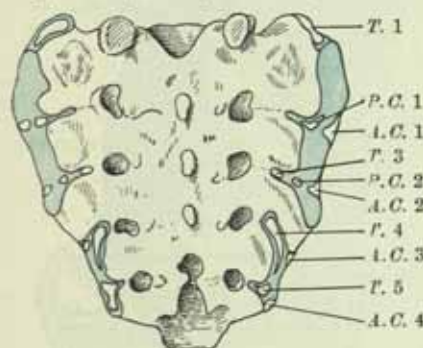
The sacrum (figs. 275 to 279).—Each sacral vertebra is ossified from three primary centres, one for the body and two for the vertebral arch. Two epiphysal plates are ossified for each body, one for the upper and the other for the lower surface.

The anterior portions of the lateral parts of the sacrum have six additional (costal) centres, two for each of the first three vertebrae; these appear above and lateral to the pelvic sacral foramina (figs. 275, 278).

Two epiphysal plates are developed on each lateral surface of the sacrum (figs. 277, 278); one for the auricular surface, and another for the thin edge of bone below this surface.

The ends of the spines of the upper three sacral vertebrae are sometimes developed from separate epiphyses, and Fawcett † has pointed out that a number of epiphyses are present in the sacrum at the eighteenth year (fig. 279). These are distributed as follows: One for each of the two mamillary processes of the first sacral vertebra; six

FIG. 279.—The epiphyses of the costal and transverse processes of the sacrum at the eighteenth year. (E. Fawcett.)



A.C. 1, 2, 3, 4, Anterior epiphyses for first, second, third and fourth costal elements. P.C. 1, 2, Posterior epiphyses for first and second costal elements. T. 1, 3, 4, 5, Epiphyses for the first, third, fourth and fifth transverse processes.

on each side, in connexion with the costal processes (two each—an anterior and a posterior—for the first and second, and one each—an anterior—for the third and fourth vertebrae); and eight, four on each side, for the transverse processes, one each for the first, third, fourth and fifth.

He is also of opinion (1) that the auricular facets on the lateral surfaces of the sacrum are in the main formed by the development and fusion of the costal epiphyses of the first and second sacral vertebrae, and (2) that the lower part of each lateral surface is formed by the extension and union of the costal epiphyses of the third and fourth, with the epiphyses of the transverse processes of the fourth and fifth sacral vertebrae.

The periods of ossification of the sacrum.—

The centres for the bodies of the first, second and third sacral vertebrae appear towards the end of the third month, and those for the bodies of the fourth and fifth vertebrae between the fifth and eighth months of

* See "The Evolution of the Vertebral Column." Edited by J. F. Gaskell and H. L. H. H. Green. Camb. Univ. Press, 1933.

† E. Fawcett, *Anat. Anz.*, 30, 1907.

eighth months of intrauterine life. The first step in the consolidation of the sacrum is the union of these separate parts of the individual vertebrae. The costal element unites with the vertebral arch, before the latter joins the centrum, and this process precedes the union of the laminae with one another. The fusion of the vertebral arches with the centra is completed at or soon after the eighth year, and traces of the neurocentral joints of the first sacral vertebra can be found after union is complete in the other vertebrae. About the same time or a little later the laminae fuse with one another, and this process usually begins above and extends in a downward direction, but it is not uncommon to find the laminae of the fourth sacral vertebra fused with one another before the process is completed in the first.

The parts of the individual vertebrae are united before puberty. At that time epiphysal centres develop (1) for the upper and lower surfaces of the bodies, (2) for the spinous processes, and (3) for the extremities of the costal and transverse process elements. At the same time the articular processes and the conjoined costal and transverse process elements begin to fuse with one another, from below upwards, but fusion of the individual vertebrae cannot be completed until the upper and lower epiphyses have united with the bodies, a process which is rarely completed before the twenty-first year. Traces of the intervertebral disc between the first and second sacral vertebrae can be found up to, and often after, middle life.

The coccyx.—Each segment of the coccyx is ossified from one primary centre. These appear as follows: in the first segment between the first and fourth years; in the second between the fifth and tenth years; in the third between the tenth and fifteenth years; in the fourth between the fourteenth and twentieth years. As age advances, the segments unite with one another, the union between the first and second being frequently delayed until the age of thirty years. At a late period of life, especially in females, the coccyx often fuses with the sacrum.

THE VERTEBRAL COLUMN AS A WHOLE

The **vertebral column** is situated in the median plane, at the posterior part of the trunk. Its average length in the male is about 70 cm.; of this the cervical part measures about 12 cm., the thoracic 28 cm., the lumbar 18 cm., and the sacrum and coccyx about 12 cm. The average length of the female vertebral column is about 60 cm.

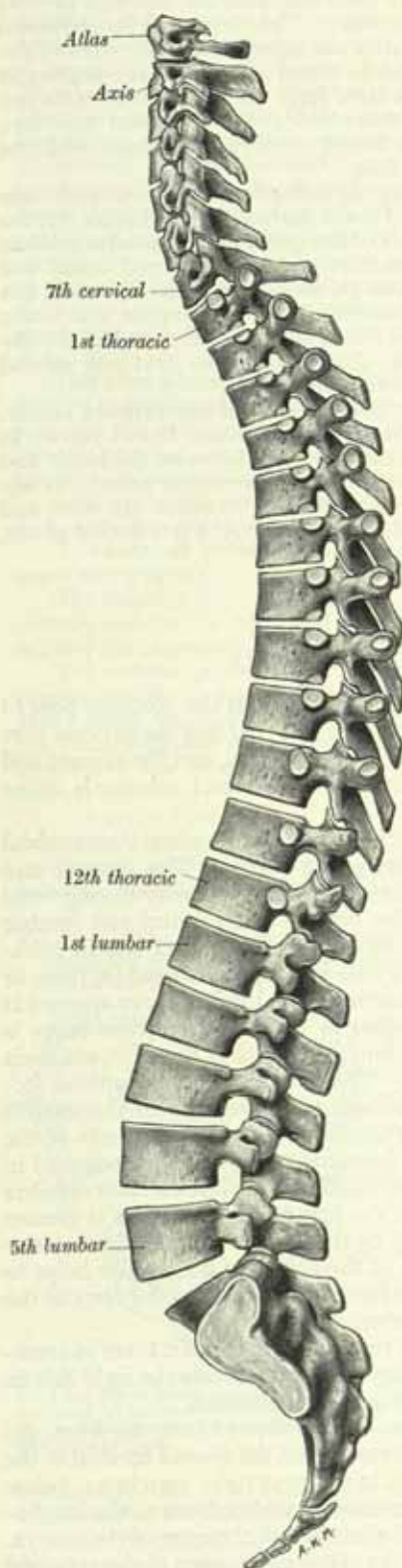
The curves of the vertebral column.—Viewed from the side (fig. 280), the vertebral column presents cervical, thoracic, lumbar, and pelvic curves. The thoracic and pelvic curves are termed primary curves, as they are concave ventrally during foetal life and retain the same type of curvature after birth. The cervical and lumbar curves are secondary or compensatory; the cervical curve appears late in intra-uterine life and is accentuated when the child is able to hold up its head (at three or four months), and to sit upright (about nine months); the lumbar curve appears at twelve to eighteen months, when the child begins to walk. The *cervical* curve is convex forwards, and is the least marked of the four; it begins at the atlas, and ends at the middle of the second thoracic vertebra. The *thoracic* curve is concave forwards, and reaches from the middle of the second to the middle of the twelfth thoracic vertebra; it is caused by the greater depth of the posterior parts of the vertebral bodies. The *lumbar* curve is convex forwards and is more pronounced in the female than in the male; it reaches from the middle of the last thoracic vertebra to the lumbosacral angle, and the convexity of the lower three segments is greater than that of the upper two; it is caused mainly by the greater depth of the anterior parts of the intervertebral discs, but the shape of the vertebral bodies also helps to produce it. The *pelvic* curve extends from the lumbosacral joint to the apex of the coccyx; its concavity faces downwards and forwards.

In the upper part of the thoracic region of the vertebral column there is sometimes a slight *lateral* curvature, with its convexity directed towards the right side in right-handed persons, and to the opposite side in the left-handed.

The anterior surface of the vertebral column.—When viewed from the front, the width of the bodies of the vertebrae is seen to increase from the second cervical to the first thoracic; there is then a slight diminution in the next three vertebrae: below this there is again a gradual and progressive increase in width down to the lumbosacral angle. From this level there is a rapid diminution, to the apex of the coccyx.

The posterior surface of the column presents the spinous processes of the vertebrae in the median plane. In the cervical region (with the exception of the second and

FIG. 280.—The vertebral column, viewed from the left side.



seventh vertebrae) these are short and nearly horizontal, with bifid ends. In the upper part of the thoracic region they are directed obliquely downwards; in the middle part they are long and almost vertical; in the lower part of the thoracic region and in the lumbar region they are nearly horizontal. They are separated by considerable intervals in the cervical and lumbar regions, but are closely approximated in the middle of the thoracic region. Occasionally a spinous process may deviate from the median plane—a fact to be remembered in practice, as irregularities of this sort occur also in fractures or displacements of the vertebral column. The seventh cervical can be felt at the lower end of the nuchal furrow, and below it the first and, usually, the second thoracic can be identified. The third thoracic lies opposite the root of the scapular spine and the seventh lies opposite the inferior angle of the scapula, provided that the arm is at rest by the side. The twelfth thoracic spinous process lies opposite the midpoint of a vertical line drawn from the inferior angle of the scapula to the iliac crest. At the sides of the spinous processes the *vertebral grooves* lodge the deep muscles of the back. In the cervical and lumbar regions these grooves are shallow and are formed by the laminae of the vertebrae; in the thoracic region they are deep and wide, and are formed by the laminae and transverse processes. Lateral to the laminae are the articular processes, and still more lateral the transverse processes. In the thoracic region the transverse processes lie on a plane considerably behind that of the same processes in the cervical and lumbar regions. In the cervical region the transverse processes are placed in front of the articular processes, lateral to the pedicles, and between the intervertebral foramina. In the thoracic region they are behind the pedicles, intervertebral foramina, and articular processes. In the lumbar region they are in front of the articular processes, but behind the intervertebral foramina. The size of the transverse processes of the atlas has already been emphasised (p. 233), and the breadth from the tip of one transverse process to the tip of the other has been contrasted with the same measurement in the axis. This measurement shows little variation from the second to the sixth cervical vertebra, but in the seventh it shows a substantial increase. In the thoracic region the measurement is greatest in the first and then gradually diminishes, being least in the twelfth, where the transverse process elements are usu-

ally reduced to mere vestiges. In the first lumbar vertebra the measurement is greater, in the second it is further increased, while in the third it is greater than it is in any of the other vertebræ. In the fourth and fifth it suffers a slight reduction.

The *lateral surfaces* of the vertebral column are separated from the posterior surface by the articular processes in the cervical and lumbar regions, and by the transverse processes in the thoracic region. The anterior part of the lateral surface of the column is formed by the sides of the bodies of the vertebræ, marked in the thoracic region by the facets for articulation with the heads of the ribs. The intervertebral foramina are placed behind the bodies and between the pedicles; they are oval in shape, smallest in the cervical and upper part of the thoracic regions, and gradually increasing in size to the last lumbar; they transmit the spinal nerves and vessels.

The *vertebral canal* follows the curves of the column; it is large and triangular in the cervical and lumbar regions, where movement is free, but small and circular in the thoracic region, where motion is more limited.

Applied Anatomy.—Although there is only a very limited amount of movement between any two contiguous vertebræ, there is a considerable range of movement in the vertebral column as a whole. The intervertebral discs act as buffers between the different segments and counteract or neutralize the effect of jars or shocks which may be applied to the column; for example, dropping from a height on to the feet rarely causes concussion of the brain or spinal cord. The security of the column is also increased by the presence of the curves, which enable it to bend without breaking. The vertebræ are so firmly united to one another that violence applied to the column is more likely to produce fracture or dislocation than a tearing of ligaments, except in the cervical region where dislocation or subluxation can occur without bony injury.

Fractures or fracture dislocations of the vertebral column are the result of (1) forced flexion, e.g. by a violent blow on the back from a large object, and (2) violence transmitted along the long axis of the column, e.g. by falling on to the feet from a height, or by diving on to the head. In the first group the injury commonly occurs at the level of T. 5 or T. 6. In the second group, owing to the normal curvature of the vertebral column, the injury is also a flexion fracture and its site is between T. 9 and L. 2. (See also p. 463).

In spondylolisthesis, which is present in 5 per cent. of skeletons,* the spine, laminae and inferior articular processes of the fifth (sometimes the fourth) lumbar vertebra are united to one another but are separate from the rest of the bone. The condition may give rise to "low back" pain and is usually regarded as due to a congenital defect. The anatomical findings have given rise to the conjecture that each half of the vertebral arch ossifies from two primary centres, which fail to fuse with each other in spondylolisthesis. There is no anatomical evidence in support of this supposition.†

THE STERNUM

General features.—The **sternum** (figs. 281 to 283) is a long flat bone, forming the median portion of the anterior wall of the thorax. Its average length is 17 cm., and is rather greater in the male than in the female. Its upper end supports the clavicles, and its margins articulate with the cartilages of the first seven pairs of ribs. It consists of three parts, named from above downwards, the *manubrium*, the *body* and the *xiphoid process*; in early life the body consists of four segments. In its natural position the inclination of the bone is oblique from above, downwards and forwards. It is slightly convex in front, and concave behind; it is broad above, narrow at the junction of the manubrium with the body, below which it gradually widens as far as the level of the articulations of the cartilages of the fifth ribs, and then narrows quickly to its lower end.

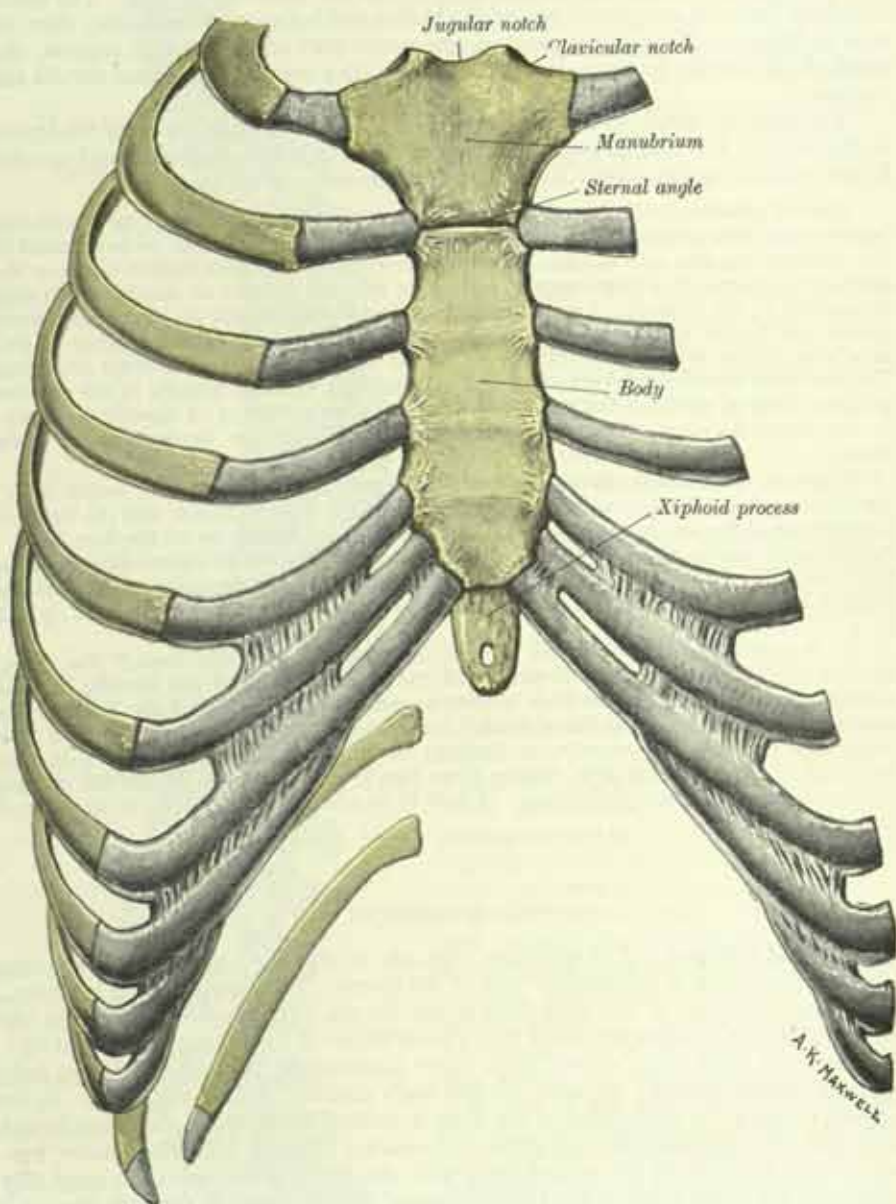
The **manubrium sterni** is of a somewhat triangular form, broad and thick above, narrow below at its junction with the body. Its *anterior surface* is smooth, convex from side to side and concave from above downwards. Its *posterior surface* is concave and featureless. The *superior border* is thick, and presents at its centre the *jugal (suprasternal) notch*; on each side of this notch there is an oval articular

* T. A. Willis, *Am. J. Anat.*, **32**, 1923.

† M. Batts, jr., *J. Bone and Joint Surg.*, **21**, 1939.

surface, directed upwards, backwards, and laterally, for articulation with the sternal end of the clavicle, and termed the *clavicular notch*. The *inferior border*, oval and rough, is covered in the recent state with a thin layer of cartilage, for articulation with the upper end of the body. The *lateral borders* are each marked above by a depression for the reception of the first costal cartilage, and below by a small articular facet, which, with a similar one on the upper angle of the body, forms a notch for the

FIG. 281.—The sternum and costal cartilages. Anterior aspect.



sternal end of the cartilage of the second rib. Between the depression for the first costal cartilage and the facet for the second, the narrow curved edge slopes from above downwards and medially. The widest part of the sternum is at the level of the first costal cartilages.

The **body** of the sternum is longer, narrower, and thinner than the manubrium, and attains its greatest breadth close to the lower end. Its *anterior surface*, nearly flat, is directed forwards and slightly upwards, and is marked by three ill-defined transverse ridges, which indicate the lines of fusion of four originally separate seg-

ments. A *sternal foramen*, of varying size and form, is occasionally seen at the junction of the third and fourth pieces of the body (p. 106). The *posterior surface*, slightly concave, is also marked by three transverse lines, less distinct, however, than those on the anterior surface. The *upper end* is oval and articulates with the manubrium at the *sternal angle*, which forms a ridge on the anterior surface that can be felt through the skin without difficulty. On the posterior surface the position of the manubrio-sternal joint is marked by a transverse groove (fig. 282). The *lower end* is narrow, and articulates with the xiphoid process. Each *lateral border* (fig. 283), at its superior angle, has a small notch, which, with a similar one on the manubrium, forms a cavity for the reception of the sternal end of the cartilage of the second rib; below this, four *costal notches* articulate with the sternal ends of the cartilages of the third, fourth, fifth and sixth ribs; the inferior angle has a small facet, which, with a similar one on the xiphoid process, forms a notch for

FIG. 282.—The sternum. Posterior aspect.

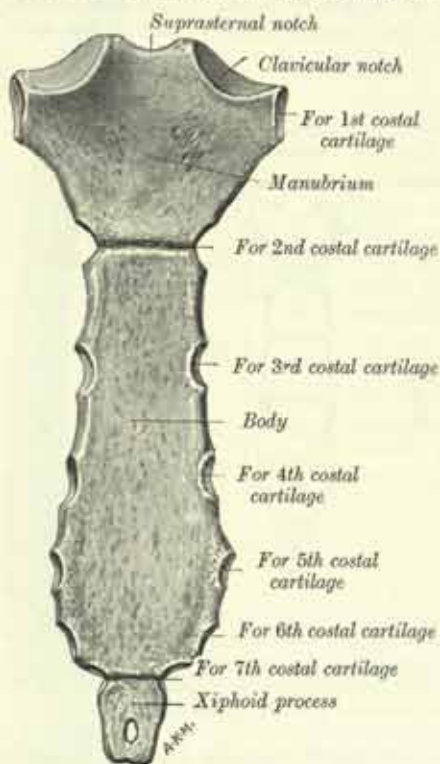
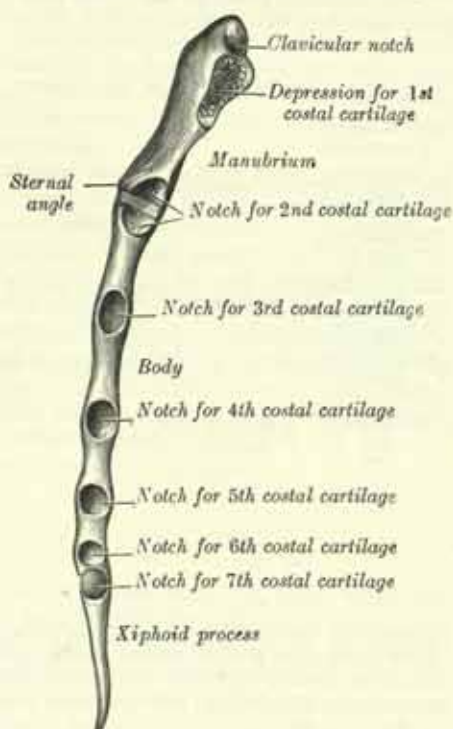


FIG. 283.—The sternum. Lateral aspect.



the reception of the cartilage of the seventh rib. These articular depressions are separated by a series of curved edges, which diminish in length from above downwards, and correspond to the anterior ends of the intercostal spaces.

The **xiphoid process** is the smallest piece of the sternum and is thin and elongated. It is cartilaginous in youth, but, at its upper part, more or less ossified in the adult. Above, it articulates with the lower end of the body of the bone, and on the front of each superior angle there is a facet for a part of the cartilage of the seventh rib (fig. 282).

The xiphoid process varies greatly; it may be broad and thin, pointed, bifid, perforated, curved, or deflected to one or other side.

Particular features.—The **manubrium** lies opposite the third and fourth thoracic vertebræ. Its *anterior surface*, on each side, gives attachment to the sternal origins of the pectoralis major and sternomastoid muscles. Its *posterior surface* gives origin to the sternothyroid muscle, opposite the first costal cartilage; above this level the most medial fibres of the sternohyoid usually arise from the bone. This surface forms the anterior boundary of the superior mediastinum and its lower part is related to the arch of the aorta, and its upper part to the left brachiocephalic vein and the brachio-

cephalic (innominate), left common carotid and left subclavian arteries. Its lateral portions are related to the lungs and pleuræ. The *jugal notch* gives attachment to some of the fibres of the interclavicular ligament. On the *lateral border* no joint cavity is interposed between the manubrium and the first costal cartilage, and the union is of the nature of a synchondrosis.

The **body** lies opposite the fifth to the ninth thoracic vertebrae. Its *anterior surface* gives attachment, on each side, to the articular capsules of the sternocostal joints and to the sternal origin of the pectoralis major muscle. Its *posterior surface* gives origin inferiorly to the transversus thoracis (sternocostalis) muscle, and presents numerous important relationships. On the right side of the median plane it is related to the right pleura and the thin, anterior border of the right lung, which intervene between it and the pericardium. To the left of the median plane the upper two pieces are related to the left pleura and lung, but the lower two are directly related to the pericardium. The *borders* give attachment to the external intercostal membranes in the intervals between the costal notches. With the exceptions of the first and the sixth, the cartilages of the true ribs articulate with the sternum at the lines of junction of its primitive component segments.

The **xiphoid process** lies in the floor of the epigastric fossa. Its *anterior surface* gives insertion to the most medial fibres of the rectus abdominis and to the apo-

FIG. 284.—The ossification of the sternum.

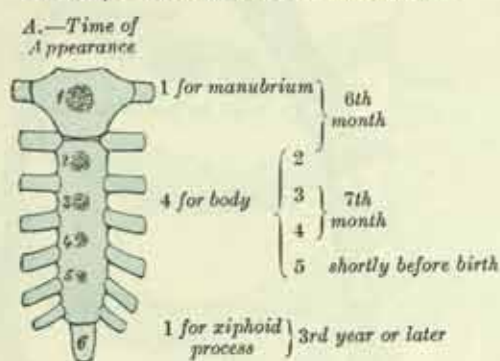
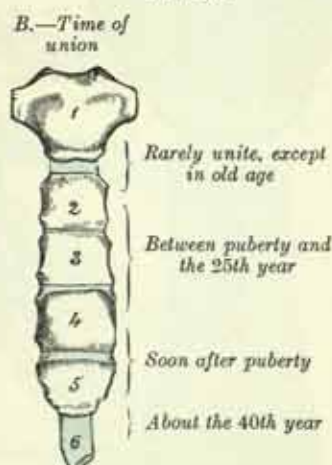


FIG. 285.



neuroses of the external and internal oblique muscles. Its *lower end* gives attachment to the linea alba, and its *borders* to the aponeuroses of the internal oblique and transversus abdominis muscles. Its *posterior aspect* gives origin, on each side, to some of the fibres of the diaphragm, and is related to the anterior surface of the liver.

Structure.—The sternum is composed of highly vascular spongy substance covered by a layer of compact bone, which is thickest on the manubrium between the clavicular notches. The spaces in the spongy substance contain *red marrow*.

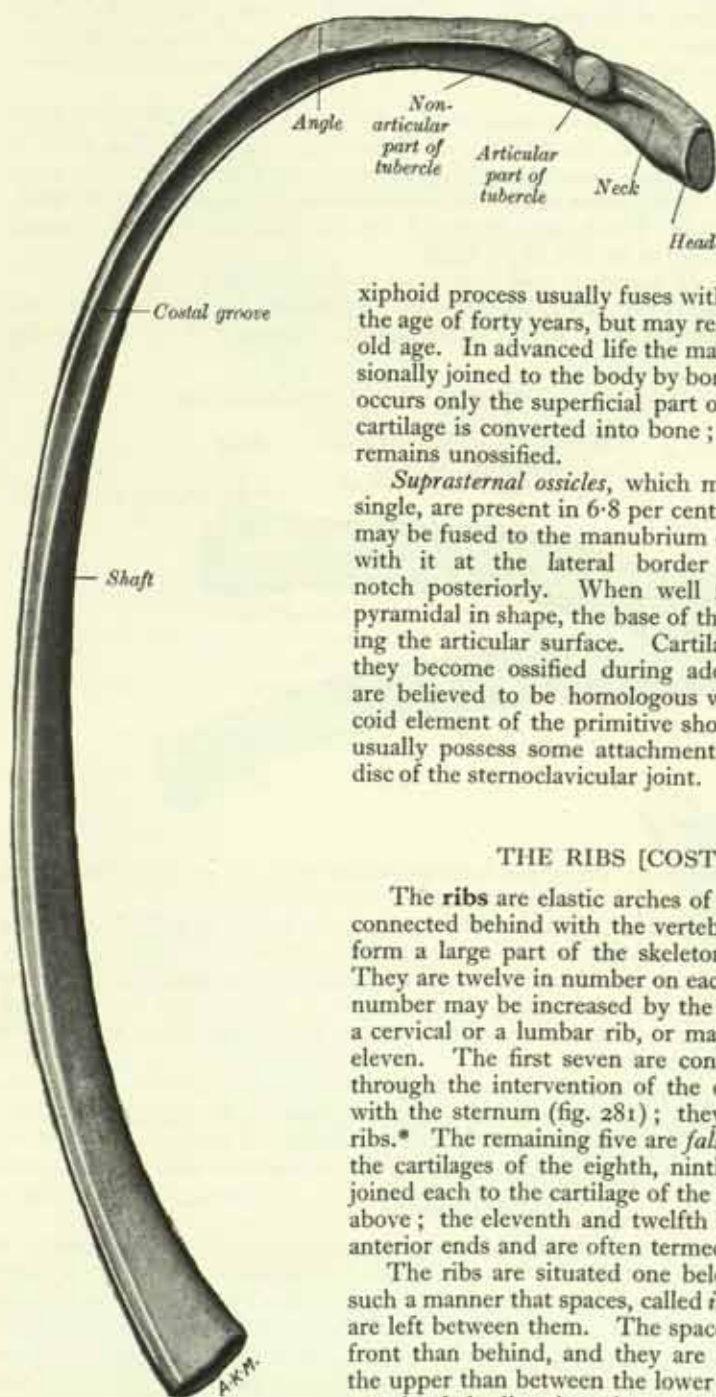
Ossification.—At an early stage of development (p. 106) the sternum consists of two cartilaginous *sternal plates*, one on each side of the median plane. Opposite the first eight pairs of ribs these plates fuse in the median plane about the eighth week to form the cartilaginous sternum, which is ossified from six centres: one for the manubrium, four for the body, and one for the xiphoid process (fig. 284).

These centres appear in the intervals between the costal notches in the following order: in the manubrium and first piece of the body, during the sixth month of intra-uterine life; in the second and third pieces of the body, during the seventh month of intra-uterine life; in the fourth piece, shortly before birth; and in the xiphoid process, in the third year or much later.* The manubrium may have two, three, or more centres; when two are present, one is generally situated above the other, the upper being the larger. The first segment of the body seldom has more than one centre; but the second, third, and fourth segments are often ossified from two laterally placed centres.

* Paterson (*The Human Sternum*, 1904) found the fourth or lowest centre for the body present only in 26.9 per cent. of cases.

Union between the centres for the body begins about puberty, and proceeds from below upwards (fig. 285); by the age of twenty-five they are all united. The

FIG. 286.—A typical rib of the left side Inferior aspect.



xiphoid process usually fuses with the body about the age of forty years, but may remain ununited in old age. In advanced life the manubrium is occasionally joined to the body by bone, but when this occurs only the superficial part of the intervening cartilage is converted into bone; the central part remains unossified.

Suprasternal ossicles, which may be paired or single, are present in 6.8 per cent. of cases. They may be fused to the manubrium or they articulate with it at the lateral border of the jugular notch posteriorly. When well formed they are pyramidal in shape, the base of the pyramid forming the articular surface. Cartilaginous at birth, they become ossified during adolescence. They are believed to be homologous with the epicoracoid element of the primitive shoulder girdle and usually possess some attachment to the articular disc of the sternoclavicular joint.

THE RIBS [COSTÆ]

The **ribs** are elastic arches of bone, which are connected behind with the vertebral column, and form a large part of the skeleton of the thorax. They are twelve in number on each side; but this number may be increased by the development of a cervical or a lumbar rib, or may be reduced to eleven. The first seven are connected in front, through the intervention of the costal cartilages, with the sternum (fig. 281); they are called *true ribs*.* The remaining five are *false ribs*; of these the cartilages of the eighth, ninth and tenth are joined each to the cartilage of the rib immediately above; the eleventh and twelfth are free at their anterior ends and are often termed *floating ribs*.

The ribs are situated one below the other in such a manner that spaces, called *intercostal spaces*, are left between them. The spaces are deeper in front than behind, and they are deeper between the upper than between the lower ribs. The ribs vary in their direction, the upper ones being less oblique than the lower; the obliquity reaches its

maximum at the ninth rib, and gradually decreases from that rib to the twelfth. The ribs increase in length from the first to the seventh, below which they diminish to

* Sometimes the eighth rib cartilage articulates with the sternum; this condition occurs more frequently on the right side than on the left.

the twelfth. In breadth they decrease successively from above downwards; in the upper ten the greatest breadth is at the anterior extremity. The first two and the last three ribs present special features, but the remaining seven conform to a common plan.

General features of the ribs (figs. 286, 287).—A rib from the middle of the series should be taken in order to study the general features of a typical rib.

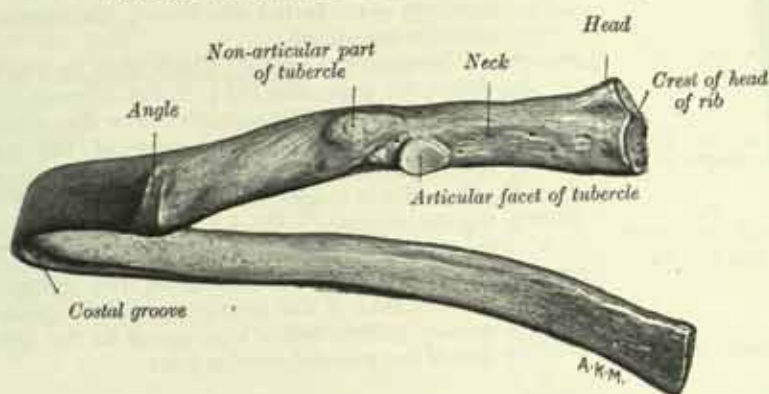
Each rib has a posterior and an anterior end, and an intervening portion—the shaft.

The **anterior end** can be distinguished by the presence of a small cup-shaped depression, which receives the lateral end of the costal cartilage. The shaft is curved with the convexity outwards, and is grooved along the lower part of its inner surface so that the lower border of the shaft is thin and sharp in contrast to the thick, rounded upper border. With this information the student is in a position to assign a typical rib correctly to its side of the body.

The **posterior or vertebral end** possesses a head, a neck and a tubercle.

The **head** presents two facets, separated by a transverse ridge, named the *crest*. The lower facet, which is the larger, articulates with the body of the numerically

FIG. 287.—A typical rib of the left side. Posterior aspect.



corresponding vertebra; the upper facet articulates with the vertebra above, and the crest of the head is placed opposite the intervertebral disc.

The **neck** is the flattened portion which succeeds the head; it lies in front of the transverse process of the numerically corresponding vertebra. It is placed obliquely so that its anterior surface faces forwards and upwards. Its posterior surface is directed backwards and downwards, and is roughened and pierced by numerous foramina. Its upper border is sharp and forms the *crest of the neck of the rib*: its lower border is rounded.

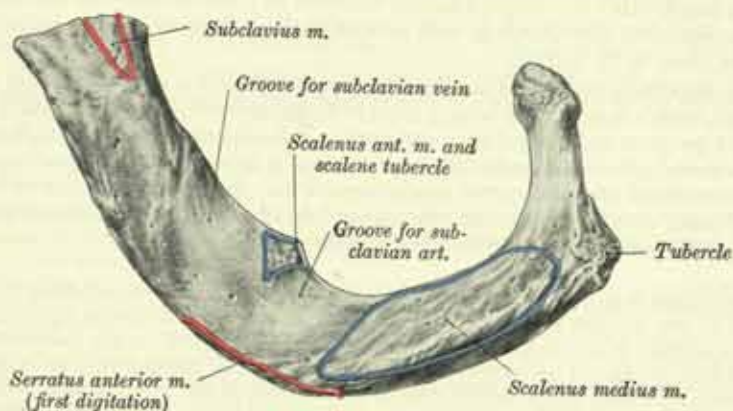
The **tubercle** is placed on the outer surface of the posterior part of the rib, at the junction of the neck with the shaft; it is more prominent in the upper than in the lower ribs and is divided into a medial articular and a lateral non-articular portion. The **articular portion** bears a small, oval facet for articulation with the transverse process of the numerically corresponding vertebra; the non-articular portion is rough for ligamentous attachments.

The **shaft** is thin and flattened, with an external and an internal surface, a superior and an inferior border. It is not only curved but is also bent, and the **angle** is situated 5–6 cm. from the tubercle. In addition, the shaft is slightly twisted in its long axis, and this may be demonstrated if the rib is placed with its lower border in contact with a horizontal surface. The part behind the angle inclines medially and upwards, and its outer surface faces downwards and backwards; in front of the angle the outer surface faces slightly upwards. The **external surface** is convex and smooth. A short distance from the tubercle it is crossed by a rough line, directed downwards and laterally, which marks the position of the angle. The **internal surface** is smooth and is marked along its lower border by a groove, termed the *costal groove*, which is bounded below by the inferior border of the shaft. The upper border of the groove is continuous behind with the lower border of the neck, but anteriorly it

terminates at the junction of the middle and anterior thirds of the shaft; in front of this point, the groove is absent.

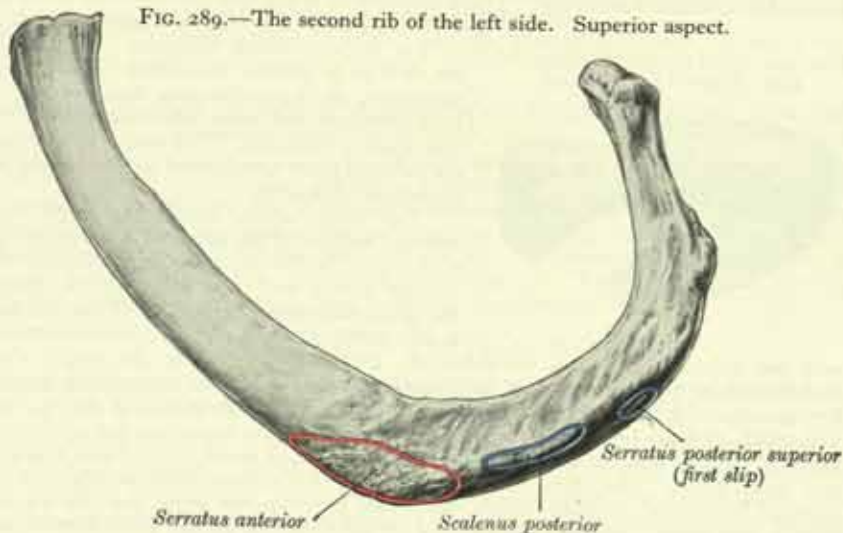
The **first rib** (fig. 288) is the most curved and usually the shortest of the ribs; it is broad and flat, its surfaces facing upwards and downwards, and its borders inwards and outwards. It is placed very obliquely in the body—sloping downward

FIG. 288.—The first rib of the left side. Superior aspect.



and forwards from its vertebral to its sternal end. The *head* is small and rounded, and bears a single, nearly circular, articular facet, which articulates with the upper part of the side of the body of the first thoracic vertebra. The *neck* is rounded, and is directed upwards, backwards and laterally. The *tubercle*, thick and prominent, is directed upwards and backwards; it bears an oval facet on its medial part for articulation with the transverse process of the first thoracic vertebra. At the tubercle

FIG. 289.—The second rib of the left side. Superior aspect.



the rib is bent, so that the head of the bone is directed slightly downwards; the angle and the tubercle therefore coincide. The *upper surface* of the shaft is crossed obliquely by two shallow grooves, separated from each other by a slight ridge, which ends at the inner border of the rib in a small projection, termed the *scalene tubercle*. The *under surface* is smooth and has no costal groove. The *outer border* is convex, thick behind, but thin in front. The *inner border* is concave and thin, and marked near its centre by the scalene tubercle. The *anterior end* is larger and thicker than that of any of the other ribs.

The **second rib** (fig. 289) is about twice the length of the first, but has a similar curvature. The non-articular portion of the *tubercle* is often small. The *angle* is

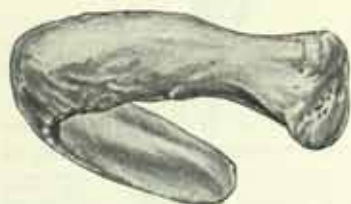
slight, and situated close to the tubercle. The *shaft* is not twisted, so that both ends of it touch any plane surface upon which the rib may be laid; but at the tubercle there is an upward convexity, similar to, but smaller than, that found in the first rib. The *external surface* of the shaft is convex, and looks upwards and a little outwards; near its middle it is marked by a rough, muscular impression. The *internal surface*, smooth and concave, is directed downwards and a little inwards; on its posterior part there is a short costal groove.

The **tenth rib** has a single articular facet on its head, which may articulate with the intervertebral disc above as well as with the upper border of the tenth thoracic vertebra close to its pedicle.

The **eleventh and twelfth ribs** (fig. 290) have each a single articular facet on the head, which is relatively large; they have no necks or tubercles; their anterior ends are pointed and tipped with cartilage. The eleventh has a slight angle and a shallow costal groove. The twelfth has neither; it is much shorter than the eleventh, and its vertebral end is directed slightly upwards. The inner surfaces of both ribs look *upwards* as well as inwards, the upward inclination being more marked in the twelfth. Sometimes the twelfth rib is shorter than the first.

Particular features.—The **head** of a typical rib gives attachment along its anterior border to the radiate ligament, and its crest to the intra-articular ligament. The anterior surface of the head is related to the costal pleura, and, in the lower ribs, to the sympathetic trunk. The *anterior surface* of the **neck** is divided into an upper and a lower area by a faint ridge, which affords attachment to the internal intercostal membrane and is continuous with the inner of the two lips on the superior border of the shaft. The upper area, of varying size and more or less triangular in shape, is separated from the internal intercostal membrane by some fatty tissue; the lower area is smooth and covered with the costal pleura. The *posterior surface* of the neck gives attachment to the costotransverse ligament and is pierced by numerous vascular foramina. The *crest of the neck* is rough for the attachment of the superior costotransverse ligament, and it can be traced laterally into the outer lip of the superior border of the shaft. The *inferior border* of the neck is rounded and can be traced laterally into the upper border of the costal groove; it gives attachment to the internal intercostal membrane. The *articular part of the tubercle* conforms to the shape

FIG. 290.—The twelfth rib of the left side. Viewed from behind.



of the articular facet on the transverse process of the corresponding vertebra. In the upper six ribs it is convex and faces backwards and medially; in the succeeding three or four ribs it is flattened and faces downwards, backwards and slightly medially. The *non-articular part of the tubercle* gives attachment to the lateral costotransverse ligament.

The ridge which marks the *angle* on the *external surface* of the **shaft** of a typical rib gives attachment to the upward continuation of the lumbar fascia and the most lateral fibres of the iliocostalis thoracis muscle. From the second to the tenth ribs the distance between the angle and the tubercle becomes progressively greater. Medial to the angle, the *external surface* gives attachment to the corresponding levator costæ and is covered by the erector spinæ (sacrospinalis) muscle. Near the sternal end of this surface an indistinct, oblique line (which marks the anterior angle) separates the origins of the external oblique and the serratus anterior (or latissimus dorsi, in the cases of the ninth and tenth ribs). The *costal groove* on the *internal surface* gives attachment to the internal intercostal muscle, which intervenes between the bone and the intercostal vessels and nerve. At the vertebral end of the bone the groove faces downwards, as its borders lie on the same plane. Near the angle the shaft broadens and the groove passes on to the internal surface. The upper edge of the groove gives attachment to the intercostalis intimus, which rarely extends on to the anterior fourth of the rib. Posteriorly this edge is continuous with the lower border of the neck. The sharp lower border of the rib gives origin to the external intercostal muscle. Its upper border is marked, posteriorly, by an inner and an outer lip: the inner lip gives attachment to both the intercostalis internus and intimus; the outer lip gives attachment only to the intercostalis externus.

The **first rib** (fig. 288) presents important particular features. The *tubercle* for the *scalenus anterior* muscle, which also extends on to the adjoining part of the *upper surface*, is placed on the internal border about its middle. The groove in front of the tubercle lodges the subclavian vein, and the irregularly roughened area which inter-

venes between it and the first costal cartilage gives attachment to the costoclavicular ligament and, more anteriorly, to the subclavius muscle. The groove behind the tubercle is occupied by the subclavian artery and, as a rule, the lower trunk of the brachial plexus.* Behind this groove a rough area which extends as far as the costal tubercle gives insertion to the scalenus medius. The obliquity of the first rib is responsible for the obliquity of the thoracic inlet and accounts for the appearance of the apex of the lung in the root of the neck.

The *outer border* of the first rib is thin anteriorly but is thicker behind, where it is covered by the scalenus posterior as it descends to the second rib for its insertion. It gives origin to the upper part of the first digitation of the serratus anterior, behind and opposite to the groove for the subclavian artery. The *inner border* gives attachment to the suprapleural membrane, which covers the cervical dome of the pleura.

The **second rib** (fig. 289) bears a rough *tubercle for the serratus anterior muscle* on its external surface just behind its midpoint; this tubercle gives origin to the lower part of the first and the whole of the second digitation. The *costal groove* is very poorly marked on the *internal surface* and is restricted to its posterior part. The second intercostal nerve lies between the second rib and the pleura in most of its course. The inner and outer lips of the upper border are distinct and are widely separated behind. Immediately in front of the poorly marked angle the outer lip is roughened to give insertion to the scalenus posterior.

The **twelfth rib** (fig. 290), although short, gives attachment to numerous muscles and ligaments. The lower part of its *anterior surface*, in its medial half to two-thirds, gives insertion to the quadratus lumborum muscle and its covering fascia. Lateral and superior to these attachments the surface is related to the costodiaphragmatic recess of the pleura. The *lower border* gives attachment to the middle lamella of the lumbar fascia and, at the lateral border of the quadratus lumborum, to the lateral lumbocostal arch (p. 585). Posteriorly, close to the head, it gives attachment to the lumbocostal ligament (p. 473), by which it is connected to the transverse process of the first lumbar vertebra. The *external surface* gives attachment to the lowest levator costæ, the longissimus thoracis, and the iliocostalis, in its medial half; more laterally, it gives insertion to the serratus posterior inferior, and origin to the latissimus dorsi and the external oblique muscle of the abdomen.

It should be observed that *the lower limit of the pleural sac crosses the anterior aspect of the twelfth rib, approximately at the point where the rib is crossed by the lateral border of the iliocostalis muscle*. The lateral extremity of the rib usually lies below the line of pleural reflection and is therefore not covered with pleura.

Structure.—The ribs consist of highly vascular spongy substance, which is enclosed in a thin layer of compact substance, and contains a large proportion of red marrow.

Ossification.—Each rib, with the exception of the first and the last two, is ossified from four centres; a primary centre for the shaft, and three secondary centres, one for the head and one each for the articular and non-articular parts of the tubercle.† The primary centre appears near the angle, towards the end of the second month of intrauterine life, and is seen first in the sixth and seventh ribs. The secondary centres for the head and tubercle appear about puberty, and unite with the shaft soon after the twentieth year. The first rib has three centres, viz.: a primary one for the shaft, a secondary centre for the head, and one for the tubercle. The eleventh and twelfth ribs, being destitute of tubercles, have each only two centres.

THE COSTAL CARTILAGES

General features.—The **costal cartilages** (fig. 291) are bars of hyaline cartilage which extend forwards from the anterior ends of the ribs and contribute very materially to the elasticity of the walls of the thorax. The first seven pairs are connected with the sternum; the eighth, ninth, and tenth are articulated each with the lower border of the cartilage immediately above; the lower two are pointed, and end in the muscular wall of the abdomen. The costal cartilages vary in their length, breadth and direction. They increase in length from the first to the seventh, and then gradually decrease to the twelfth. They diminish in breadth from the first to the last, like the intervals between them. They are broad at their attachments to the ribs, and taper towards their medial extremities, with the exception of the first and second which are of the same breadth throughout, and the sixth, seventh, and eighth which are enlarged where their margins are in contact. The first cartilage descends

* The intimate relationship of the artery to the first rib is often denied, but it can be demonstrated in most subjects in the dissecting room.

† E. Fawcett states that "in all probability there is usually no epiphysis on the non-articular part of the tuberosity below the sixth or seventh rib" (*Journal of Anatomy and Physiology*, vol. xlv).

a little, the second is horizontal, the third ascends slightly, while the others are angular, continuing the course of the ribs for a short distance, and then inclining upwards to the sternum or preceding cartilage.

Particular features.—Each costal cartilage has two surfaces, two borders, and two ends. The *anterior surface* is convex, and faces forwards and upwards: that of the first gives attachment to the sternoclavicular articular disc, the costoclavicular ligament and the subclavius muscle; those of the first six or seven at their medial ends, to the pectoralis major muscle. The others are covered by, and give partial attachment to, some of the flat muscles of the anterior abdominal wall. The *posterior surface* is concave, and directed backwards and downwards; that of the first gives attachment to the sternothyroid, those of the second to the sixth inclusive to the transversus thoracis, and the six lower ones to the transversus abdominis and the diaphragm. The *superior border* is concave, and the *inferior* convex; they afford attachment to the internal intercostal muscles, and the external intercostal membranes. The inferior borders of the sixth, seventh, eighth and ninth cartilages present heel-like projections at the points of greatest convexity; a similar projection is frequently present on the lower border of the fifth cartilage. On these projections are oblong facets which articulate respectively with facets on slight projections from the superior borders of the sixth, seventh, eighth, ninth, and tenth cartilages. The *lateral end* of each cartilage is continuous with the osseous tissue of the corresponding rib. The *medial end* of the first is continuous with the sternum; the medial ends of the six succeeding cartilages are rounded and articulate with the shallow costal notches on the lateral margins of the sternum. The medial ends of the eighth, ninth, and tenth costal cartilages are pointed, and each is connected with the cartilage immediately above. Those of the eleventh and twelfth are pointed and free.

In old age the costal cartilages are prone to undergo superficial ossification.

THE THORAX

The skeleton of the **thorax** or **chest** (fig. 291), is an osseocartilaginous cage which contains and protects the principal organs of respiration and circulation. It is conical in shape, narrow above and broad below, flattened from before backwards, and longer behind than in front. It is reniform on horizontal section on account of the forward projection of the vertebral bodies.

Boundaries.—*Posteriorly* it is formed by the twelve thoracic vertebræ and the posterior parts of the ribs. At each side of the vertebral column there is a wide and deep groove in consequence of the lateral and backward direction which the ribs follow from their vertebral extremities to their angles. *Anteriorly* it is formed by the sternum, the anterior ends of the ribs and the costal cartilages, and this surface is flattened or slightly convex. *Laterally* it is convex, and is formed by the ribs. The ribs and costal cartilages are separated from each other by the intercostal spaces, eleven in number, which are occupied by the intercostal muscles and membranes.

The *inlet* of the thorax is reniform in shape; its anteroposterior diameter is about 5 cm., its transverse about 10 cm. It slopes downwards and forwards, and is bounded by the first thoracic vertebra behind, the superior border of the manubrium sterni in front, and the first rib on each side. The *outlet* is bounded by the twelfth thoracic vertebra behind, by the twelfth and eleventh ribs at the sides, and in front by the cartilages of the tenth, ninth, eighth, and seventh ribs, which ascend on each side and form an angle, termed the *infrasternal angle*. The outlet is wider transversely than from before backwards, and slopes obliquely downwards and backwards; it is closed by the diaphragm, which forms the floor of the thorax.

The thorax of the female differs from that of the male as follows: 1. Its capacity is less. 2. The sternum is shorter, and its upper margin is on a level with the lower part of the body of the third thoracic vertebra, whereas in the male it is on a level with the lower part of the body of the second. 3. The upper ribs are more movable and so allow a greater expansion of the upper part of the thorax.

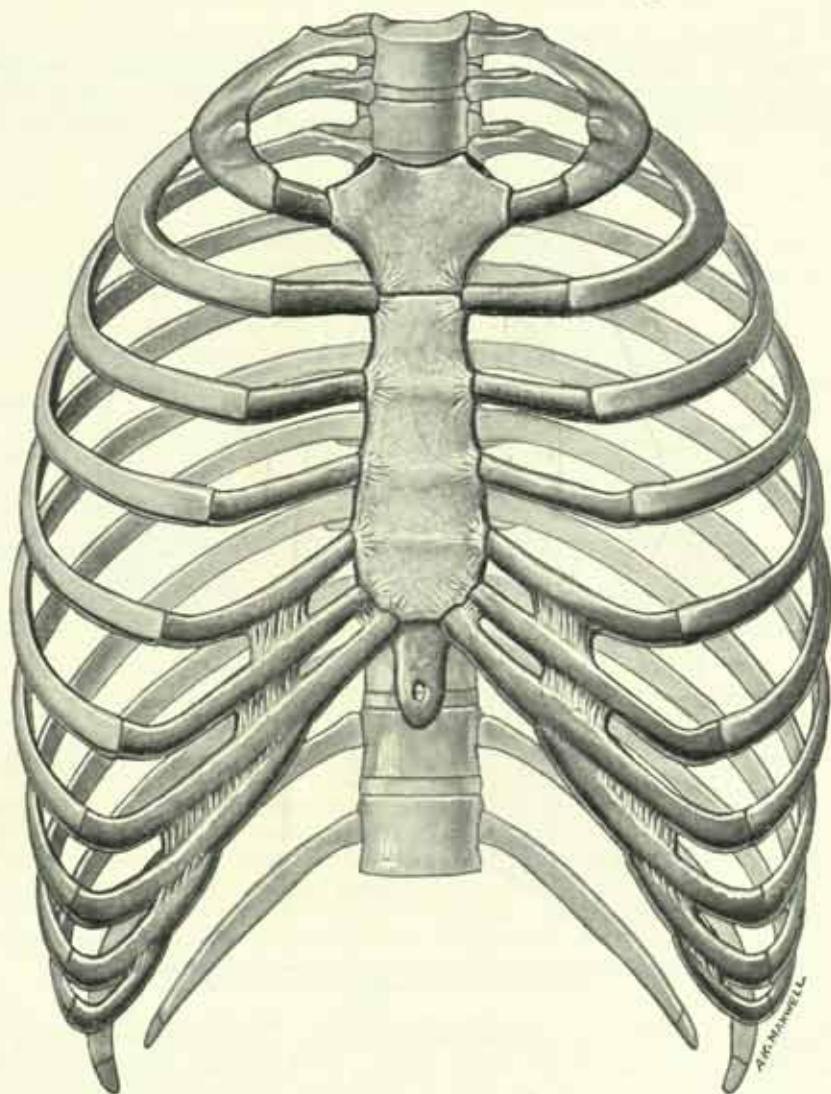
Applied Anatomy.—Fracture of the sternum is by no means common, owing, no doubt, to the elasticity of the ribs and their cartilages, which support it like so many springs.

The ribs are frequently broken, though from their connexions and shape they are able to withstand great force, yielding under pressure and recovering themselves like a spring. The middle ribs are the most liable to fracture. The fracture generally occurs from indirect violence from forcible compression of the chest walls, and the bone then gives way at its weakest part, i.e. just in front of the angle. But the ribs

may also be broken by direct violence, in which case the bone is driven inwards at the point of impact. Fracture of the ribs is frequently complicated with some injury to the viscera contained within the thorax or upper part of the abdominal cavity; this is most likely to occur in fractures from direct violence.

Cervical ribs derived from the seventh cervical vertebra (p. 106) are of not infrequent occurrence, and are important clinically because they may give rise to nervous

FIG. 291.—The skeleton of the thorax. Anterior aspect.



or vascular symptoms. The cervical rib may be a mere epiphysis articulating only with the transverse process of the vertebra, but more commonly it consists of a definite head, neck and tubercle, with or without a shaft. It extends laterally, or forwards and laterally, into the posterior triangle of the neck, where it may terminate in a free end or may join the first thoracic rib, the first costal cartilage, or the sternum.* It varies much in shape, size, direction, and mobility. If it reaches far enough forwards, its relations are similar to those of the first thoracic rib; part of the brachial plexus and the subclavian artery and vein cross over it, and are apt to suffer compression in so doing. Pressure on the plexus affects the eighth cervical and first thoracic nerves, causing paralysis of the muscles they supply, and neuralgic pains, trophic changes and paræsthesia in the area of skin to which they are distributed: no oculo-pupillary changes are to be found.

* W. Thorburn, *The Med. Chronicle*, Manchester, 4th series, xiv, 1907.

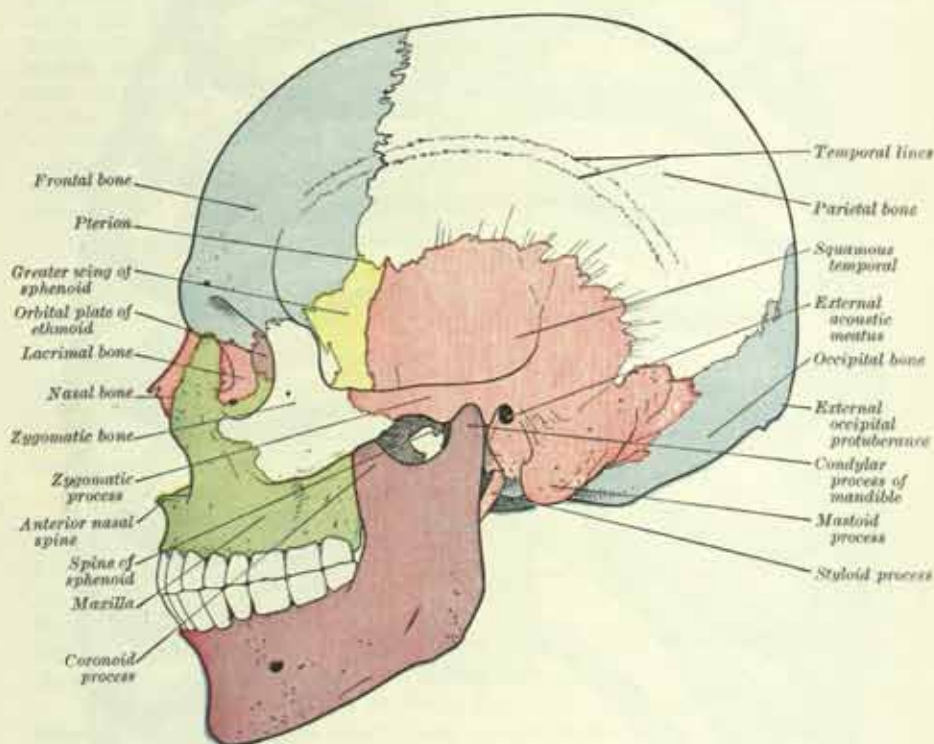
THE SKULL

INTRODUCTORY

The paragraphs which follow are intended primarily for the student who has no previous knowledge of the skull,* and may well be omitted by those who are already familiar with its principal features. The detailed description of the skull commences on p. 269.

The skull is the skeleton of the head. It is made up of a large number of bones which, with the exception of the mandible or lower jaw, are so intimately connected to one another that no movement is possible between them. The lines along which the individual bones meet one another are, for the most part, very irregular and are

FIG. 292.—The skull. (Norma lateralis). Compare with fig. 303.



NOTE: blue=frontal and occipital; pink=temporal, lacrimal and nasal; magenta=mandible and ethmoid; green=maxilla; yellow=sphenoid.

frequently serrated like the edge of a saw (fig. 296). These immovable joints between the bones of the skull are termed *sutures*. They are easily seen in the skulls of young adults, but, as old age approaches, contiguous bones tend to fuse with each other and the suture lines become more or less obliterated.

When the mandible is left out of account the remainder of the skull, strictly speaking, constitutes the cranium, but in this textbook, as well as in many others, the term skull is widely used with the same significance. The upper part of the cranium forms a box to enclose and protect the brain, and is often termed the *calvaria*. The remainder of the skull forms the *facial skeleton*, of which the upper part is immovably fixed to the calvaria and the lower part is the freely movable mandible.

The skull, considered as a whole, is of much greater importance to the student of medicine than the individual bones of which it is made up. Nevertheless, the position of the individual constituents must be determined before the student can be in a position to follow the more detailed description.

* See also note on p. 228.

The skull as a whole may be viewed from above (*norma verticalis*), from below (*norma basalis*), from behind (*norma occipitalis*), from in front (*norma frontalis*) and from the side (*norma lateralis*). The roof of the calvaria, or *skull-cap*, may be removed and the *interior of the skull* may be examined. In the erect attitude the lower margins of the orbital openings and the upper margins of the external acoustic meatuses lie on the same horizontal plane, and it is important that the student should bear this in mind when he is examining the various aspects of the skull.

The region of the forehead is formed by the **Frontal bone** (fig. 292), which passes backwards in the vault of the skull as far as the *coronal suture*, where it meets the anterior borders of the right and left **Parietal bones**. These two bones together form the greater part of the top of the head, and they articulate with each other at the serrated *sagittal suture*. Posteriorly they extend backwards to meet the **Occipital bone**, which forms the back of the head. Owing to the Λ figure formed by the meeting of the sagittal with the parieto-occipital sutures, the latter are named the *lambdoid suture*. Each parietal bone extends downwards on the side of the vault until it meets the upper limit of the *greater wing* of the **Sphenoid bone** in front, and the *squamous part* of the **Temporal bone** behind. When the skull cap is removed, the section passes through the frontal bone and usually cuts across the lower part of the parietal bone, but it may involve the squamous part of the temporal bone. Posteriorly the section cuts the occipital bone. Consequently, the *skull cap* consists of (1) a large part of the frontal bone, (2) most of the two parietal bones, (3) possibly, small parts of the squamæ of the temporal bones, and (4) a small part of the occipital bone.

When the skull cap is removed, the floor of the calvaria, almost invariably termed the **base of the skull**, is exposed. It shows a natural subdivision into three areas, which are named the anterior, middle and posterior cranial fossæ (fig. 293). The **anterior cranial fossa** forms less than the anterior third of the base and is limited behind by a sharp edge on each side of the median plane. It is important to observe that the floor of the anterior cranial fossa constitutes the roof of the orbit, on each side, and the roof of the nasal cavity, in the median area. On each side of the median plane an *orbital part* projects backwards from the **Frontal bone** and constitutes most of the roof of the orbit. These two plates are separated by a relatively narrow interval, which is occupied by a perforated strip of bone. This is termed the *cribriform plate* of the **Ethmoid bone**; it forms a large part of the roof of the nose, while the rest of the bone to which it belongs participates in the formation of the side walls of the nose. In the median plane the cribriform plate bears a crestlike elevation on its upper surface, termed the *crista galli*. The most posterior part of the floor of the anterior cranial fossa is formed by the **Sphenoid bone**. In the median area the front of the *body* of the sphenoid meets the cribriform plate of the ethmoid. On each side a narrow *lesser wing* projects laterally from the body of the sphenoid and meets the posterior margin of the orbital part of the frontal bone. It is the sharp posterior border of the lesser wing of the sphenoid bone which forms the posterior limit of the floor of the anterior cranial fossa on each side of the median plane.

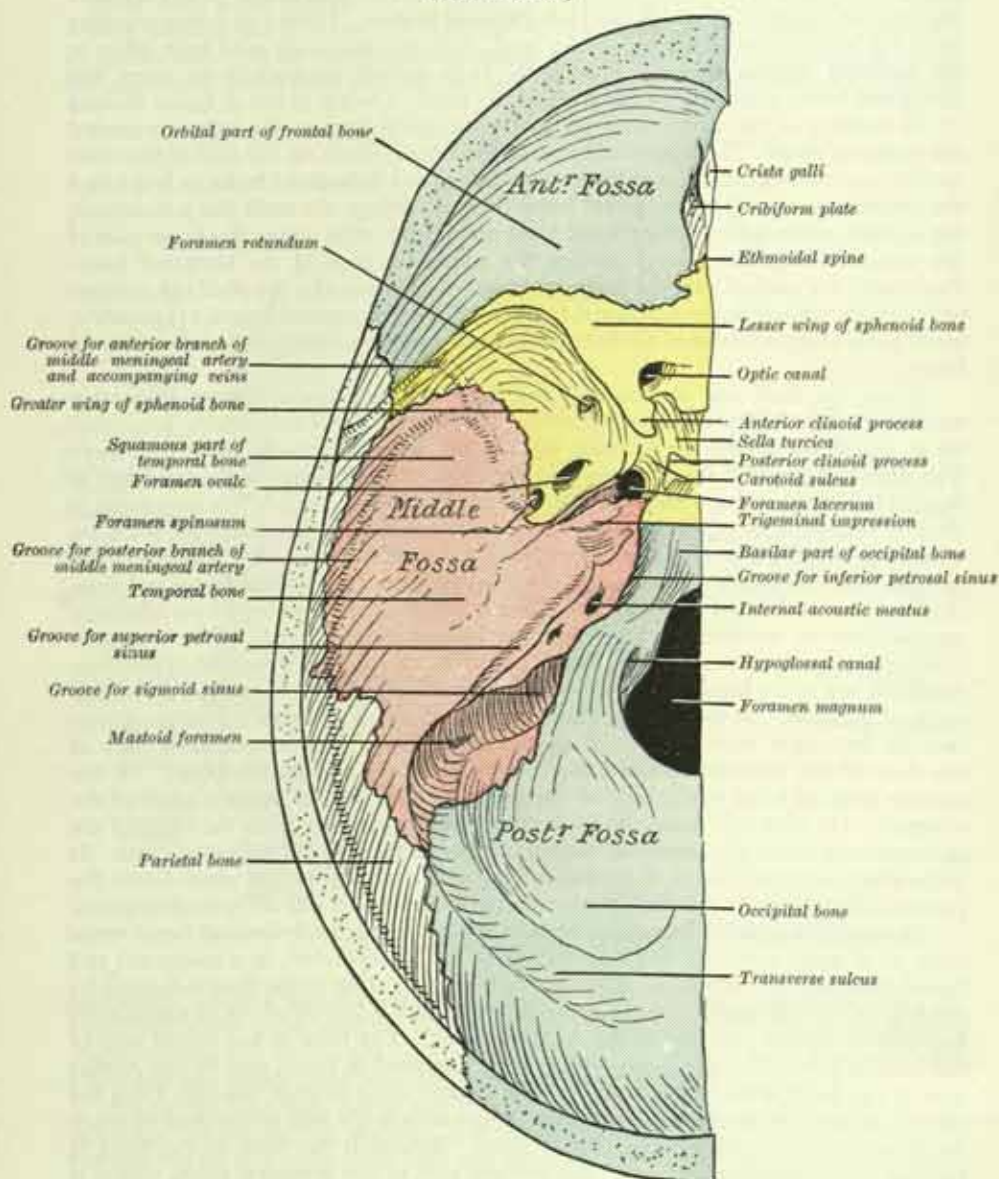
The **middle cranial fossa** (fig. 293), which lies immediately behind the anterior fossa, is of small extent in the median region but is expanded, in a backward and lateral direction, on each side. The narrow median portion of the floor is formed by the *body* of the **Sphenoid**, the upper surface of which is hollowed out to contain the hypophysis cerebri—an important ductless gland. The floor of the lateral part of the fossa is formed by the *greater wing* of the sphenoid in front, and by the *petrous part* of the **Temporal bone** behind. The greater wing extends laterally from the side of the body of the sphenoid and curves upwards in the side of the skull to reach the antero-inferior part of the parietal bone. Behind it the floor of the fossa is formed by the anterior surface of the petrous part of the temporal bone, which is continuous laterally with the squamous part of the same bone.

The **posterior cranial fossa** (fig. 293) is almost circular in outline and occupies roughly two-fifths of the base of the skull. It is formed to a very large extent by the **Occipital bone**. The large opening in its floor, termed the **foramen magnum**, is placed entirely within that bone and allows the brain to become continuous with the spinal medulla. The anterior part of the fossa is formed by the *basilar part* of the occipital bone, which is fused in front with the posterior part of the sphenoid bone. On each side the lateral wall of the fossa is formed by the posterior surface of the petrous part of the temporal bone above, and by the *lateral (condylar) part* of the

occipital bone, below. The *mastoid part* of the temporal bone, which lies immediately behind the petrous part, helps the *squamous part* of the occipital bone to complete the fossa.

When the skull is viewed from in front (*norma frontalis*, fig. 294) the **orbits**, which lodge the eyeballs, and the anterior aperture of the **nose**, can easily be identified. The part below the mouth is formed entirely by the *body* of the **Mandible**;

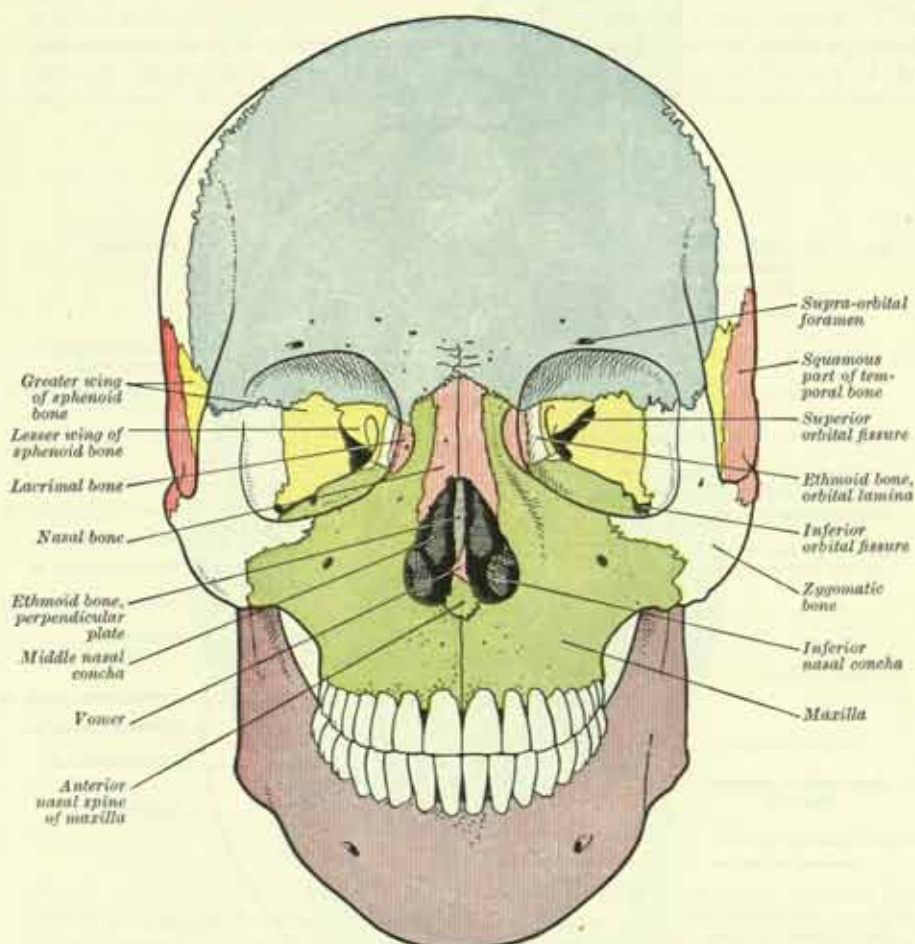
FIG. 293.—The internal surface of the left half of the base of the skull. (Basis cranii interna.)



the part above the mouth is formed almost entirely by the **Maxillæ**, or upper jaws. These bones form the upper boundary of the mouth, and the lower and lateral boundaries of the anterior nasal aperture. In addition, on each side the maxilla forms the medial part of the lower margin of the orbit, which it helps the **Zygomatic bone** to complete, while its frontal process ascends in the medial margin of the orbit to reach the **Frontal bone**. The frontal processes of the two maxillæ are separated from each other by the two **Nasal bones**, which form the upper boundary of the anterior nasal aperture.

When the skull is viewed from the side (*norma lateralis*, fig. 303) the **ramus** of the **Mandible**, which passes from the posterior end of the body of the bone upwards and slightly backwards to reach the cranium, can be identified without difficulty. The **head** of the mandible, which lies at the upper end of the posterior border of the ramus, is received into the *articular fossa* on the under surface of the squamous part of the temporal bone. The back of the mandibular head is separated from the ear passage, termed the *external acoustic meatus*, by the *tympanic part* of the temporal bone. Above and in front of the meatus the *zygomatic process* of the temporal bone passes forwards to meet the zygomatic or cheek bone, and the two form the

FIG. 294.—The skull. Anterior aspect. (*Norma frontalis*.)



Blue = frontal bone; Yellow = sphenoid bone; Green = maxilla; Pink = lacrimal, nasal, temporal bones and vomer; Mauve = Mandible; Uncoloured = parietal, zygomatic and ethmoid bones.

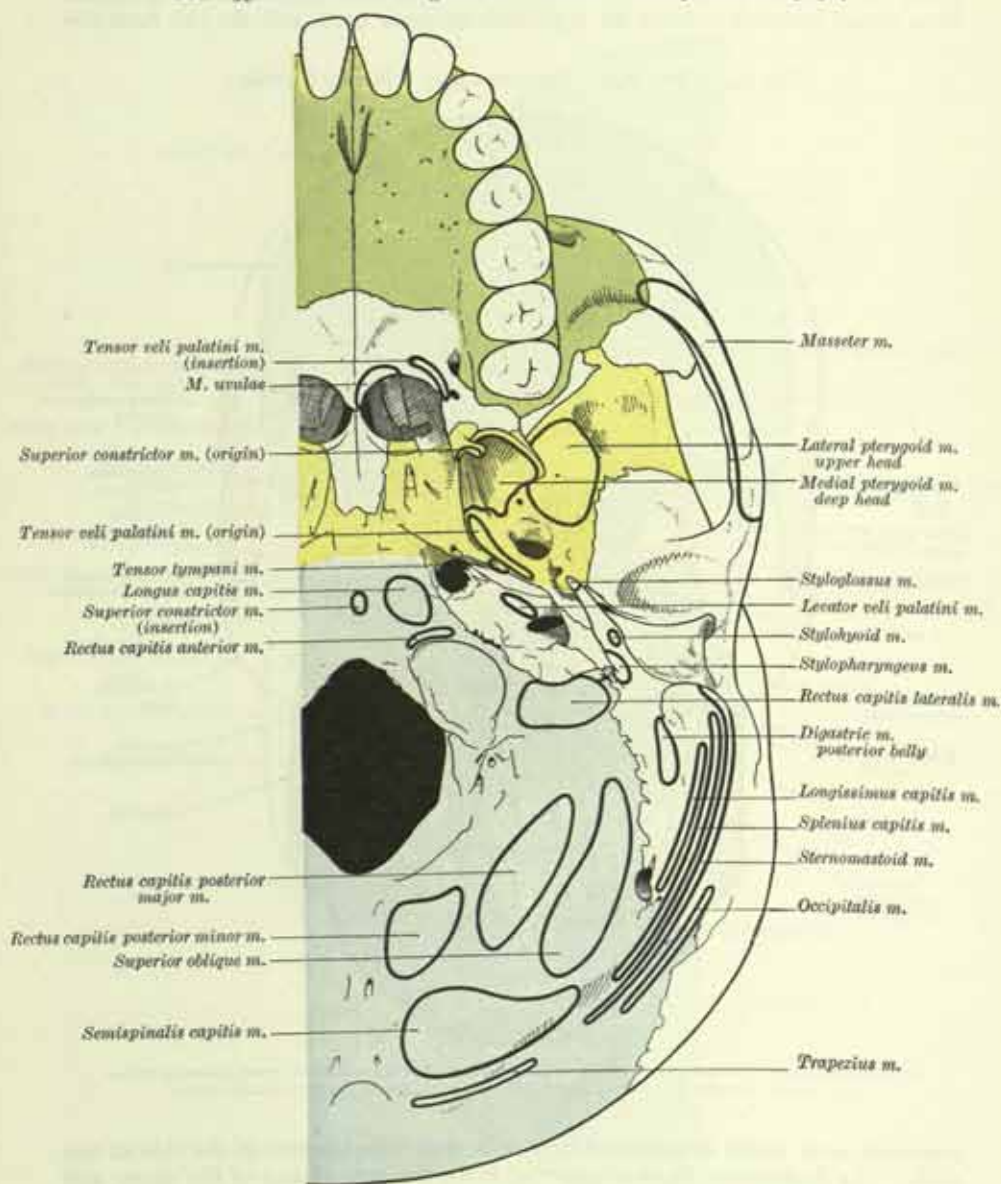
zygomatic arch, which is separated by a wide gap from the rest of the side of the skull. The **Zygomatic bone** is responsible for the prominence of the upper and anterior part of the cheek. It forms the lateral part of the lower margin of the orbital opening, as already stated, and ascends in the lateral margin to meet the **Frontal bone**.

When the mandible is removed (fig. 306) a process of bone can be seen immediately behind the maxilla and above the level of the maxillary teeth. This is the **pterygoid process**, which projects downwards from the **Sphenoid** along the line of union of its greater wing with its body. It consists of a large lateral plate with a smaller, medial plate on its medial side.

The inferior aspect of the cranium (*norma basalis*, fig. 295) is termed the **external aspect** of the base of the skull. It should be examined next. Posteriorly the

Occipital bone, with the foramen magnum, can be located without difficulty. Lateral to the foramen magnum the occipital bone articulates with the *posterior part* of the **Temporal bone**. Antero-laterally it articulates with the *petrous part*, which extends forwards almost to the root of the *pterygoid process*. In the anterior part of the inferior aspect of the cranium, the **bony palate**, which lies in the roof of the mouth, can be seen within the arch of the teeth of the maxilla. Four bones contri-

FIG. 295.—Outline drawing of *norma basalis*. Compare with fig. 307.



bute to its formation, viz., the two **Maxillæ** and the two **Palatine bones**. The anterior three-fourths of the bony palate are formed by the *palatine processes* of the maxillæ, which meet each other in the median plane; the posterior fourth is formed by the *horizontal plates* of the *palatine bones*. The palatine bones are now seen, in part, for the first time; their *perpendicular plates* are still hidden as they ascend, on each side, from the lateral border of the horizontal plate to form the posterior part of the lateral wall of the nose.

The **Lacrimal bone**, which lies in the anterior part of the medial wall of the orbit, the **Vomer**, which forms a large part of the nasal septum (fig. 315), and the

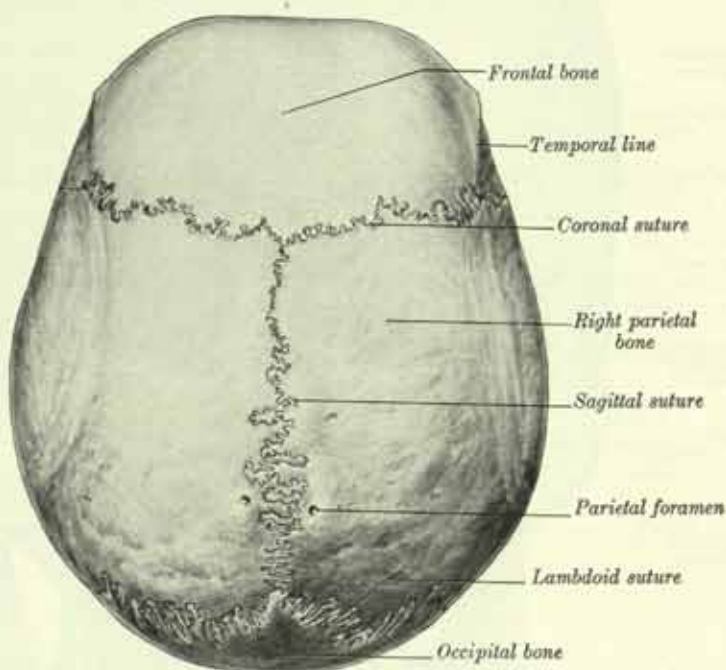
Inferior Concha, which lies in the lateral wall of the nasal cavity, can be seen only when the orbits and the nose are examined (pp. 274 and 300). With these exceptions all the bones of the skull have now been identified, and the student is in a position to undertake profitably a more detailed study of the skull as a whole.

THE EXTERIOR OF THE SKULL

NORMA VERTICALIS (fig. 296)

The outline of the skull, as seen from above, varies greatly in different specimens. In some the outline is more or less oval: in others it is more nearly circular, but its greatest width is usually nearer to the occipital than to the frontal region. This aspect of the skull is traversed by three sutures. (1) The *coronal suture* is placed between the posterior edge of the frontal bone and the anterior borders of the parietal bones. From the median plane it passes downwards and forwards across the

FIG. 296.—The skull, viewed from above.



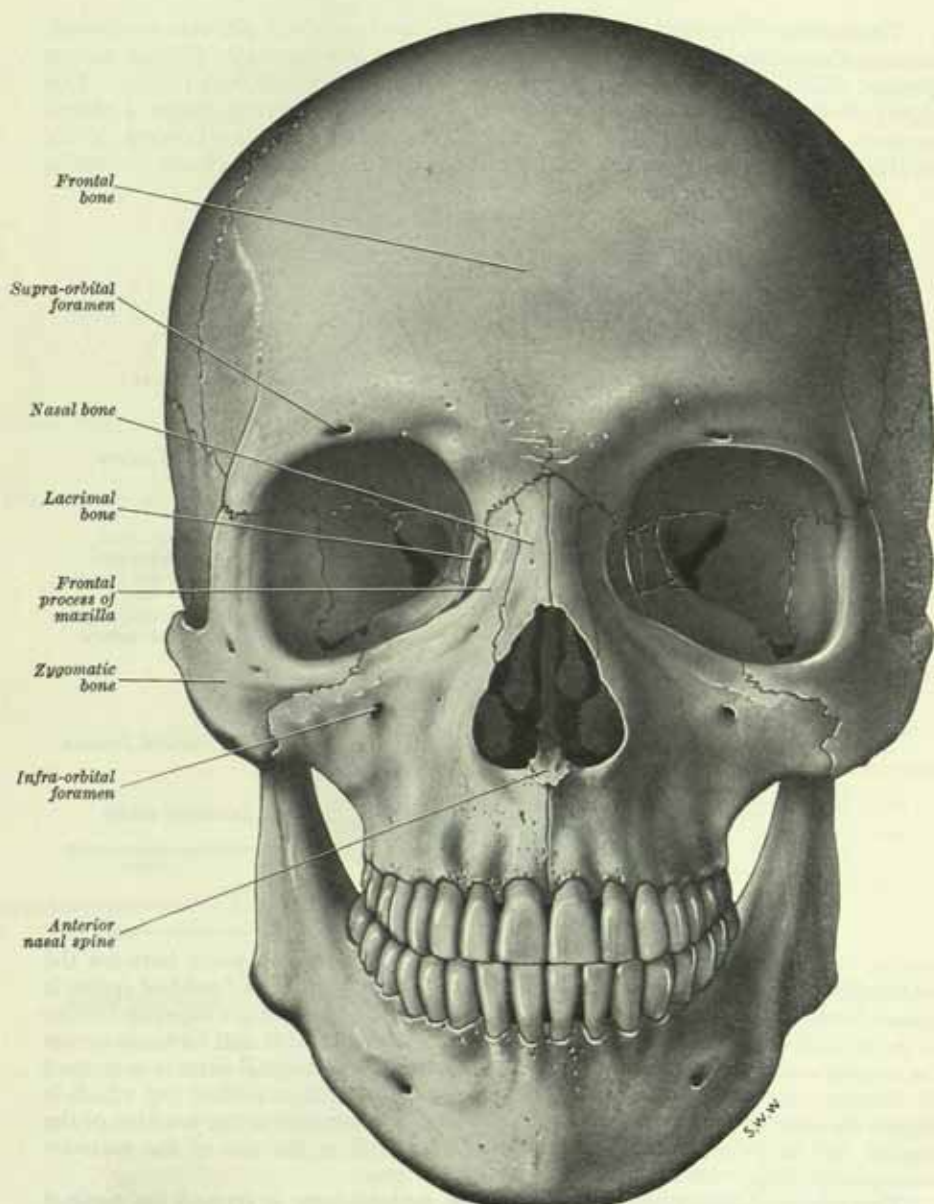
cranial vault. (2) The *sagittal suture* is placed in the median plane between the interlocking upper borders of the two parietal bones. (3) The *lambdoid suture* is placed between the posterior borders of the parietal bones and the superior border of the squamous part of the occipital bone. It runs downwards and forwards across the cranial vault. The meeting-place of the coronal and sagittal sutures is termed the *bregma*, and in the fetal skull it is the site of a membrane-filled gap which is named the *anterior fontanelle* (p. 352). The *lambda* is situated at the junction of the sagittal and lambdoid sutures and in the fetal skull is the site of the *posterior fontanelle* (p. 353), which is a similar but smaller gap.

The region of maximum convexity of the parietal bone is termed the *parietal tuber (eminence)* and can be identified easily in the living subject. In this situation the norma verticalis passes into the norma lateralis and the norma occipitalis, but there are no sharp lines of demarcation. The *parietal foramen*, which may be absent on one or both sides, pierces the parietal bone near the sagittal suture about 3.5 cm. in front of the lambda. It transmits a small emissary vein from the superior sagittal sinus within the skull, and this vessel constitutes one of the important connexions between the extra- and the intracranial veins. Anteriorly the norma verticalis slopes down into the norma frontalis.

NORMA FRONTALIS (fig. 297)

Viewed from in front the skull exhibits a more or less oval outline, wider above than below. Its upper part is formed by the frontal bone and is smooth and convex. Its lower part is very irregular and is interrupted by the orbits and the anterior bony

FIG. 297.—The skull. Anterior aspect. (Norma frontalis.)
Compare with fig. 298.

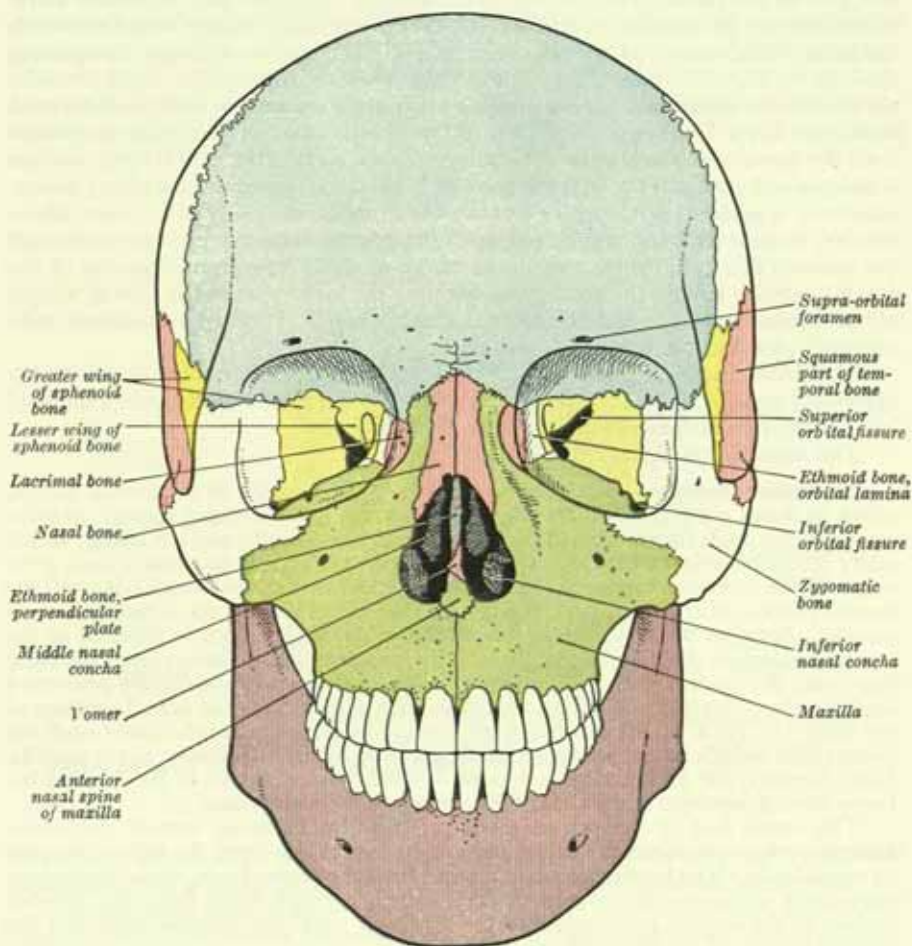


aperture of the nose. Immediately above the medial part of each orbit the *superciliary arch* forms a rounded elevation, better marked in the male than in the female skull, and these two arches are connected by a median elevation termed the *glabella*. Below the glabella the skull recedes to the point where the nasal bones meet the frontal, forming the floor of a depression at the root of the nose. The point where the internasal and frontonasal sutures meet is named the *nasion*. Above the superciliary arch on each side there is a slight rounded elevation termed the *frontal*

tuber. All these are bony landmarks which can be felt without difficulty in the living subject, and the glabella and nasion provide reference points for the surgeon in certain intracranial operations.

The **orbital opening** is more or less quadrangular in shape. Its *supra-orbital margin* is formed entirely by the frontal bone and, at the junction of its sharp lateral two-thirds with its rounded medial third, it presents the supra-orbital notch (or foramen, as the case may be), which transmits the supra-orbital vessels and nerve. The *lateral margin* is formed almost entirely by the frontal process of the zygomatic

FIG. 298.—Key to fig. 297.



Note.—Pink=nasal, vomer and lacrimal bones, and squamous temporal; Yellow=sphenoid bone; Blue=frontal bone; Green=maxilla; Magenta=mandible.
The parietal, zygomatic and ethmoid bones are uncoloured.

bone, but it is completed above by the zygomatic process of the frontal bone, and the suture which connects these two bones can be felt in the living subject as a slight depression. The zygomatic bone laterally, and the maxilla medially, share in the formation of the *infra-orbital margin*. Both these margins are sharp and can be felt easily through the skin. The *medial margin* is not so clear-cut; it is formed above by the frontal bone and below by the lacrimal crest of the frontal process of the maxilla, which is sharp and distinct in its lower half only.

The **piriform (anterior bony) aperture of the nose** is pear-shaped, wider below than above and bounded by the nasal bones and the maxillæ. The two nasal bones articulate with each other in the median plane and both articulate with the frontal bone above. On each side the nasal bone articulates behind with the frontal process of the maxilla, but its lower border, to which the lateral nasal cartilage (fig.

1003) is attached in the fresh specimen, is free and forms the upper boundary of the piriform aperture.

The maxillæ take a very large share in the formation of the skeleton of the face, and it is the growth of these bones which is responsible for the elongation of the face that occurs between the ages of 6 and 12. It is only the anterior surface of the maxilla which is visible in the norma frontalis. Medially this surface presents the well-marked *nasal notch*, which forms the lower border and the adjoining part of the lateral border of the piriform aperture of the nose. A prominent, sharp projection marks the meeting of the two maxillæ in the lower boundary of the aperture and is termed the *anterior nasal spine*. It can be identified in the lower border of the free part of the nasal septum in the living subject. About 1 cm. below the infra-orbital margin the maxilla is perforated by the *infra-orbital foramen*, which transmits the infra-orbital vessels and nerve; it lies on, or just lateral to, a vertical line passing through the supra-orbital notch. The *alveolar process* of the maxilla, which provides the sockets for the maxillary teeth, can be examined most satisfactorily in the norma basalis (p. 282). The *zygomatic process* of the maxilla is a short but stout projection from the upper and lateral part of the anterior surface of the bone. Its upper surface is oblique and articulates with the zygomatic bone at the zygomaticomaxillary suture. Inferiorly it presents a free lower border, which meets the body of the bone above the first molar tooth, and can be palpated through the skin of the cheek or through the mucous membrane of the vestibule of the mouth. The *frontal process* of the maxilla ascends behind the nasal bone, forming the lower part of the medial margin of the orbital opening, and reaches the frontal bone. It will be examined subsequently, both in the orbit and in the nose.

The *prominence of the cheek* below and lateral to the orbit is produced by the zygomatic bone. It is the convex lateral surface of the bone which can be examined both in the norma frontalis and in the norma lateralis.

The mandible is described on p. 303.

Particular features.—The *glabella* may show the remains of the frontal suture, which in about 9 per cent. of skulls extends upwards to the coronal suture. It indicates that the adult frontal bone is formed by the fusion of right and left halves, which ossify independently of each other. The medial part of the *superciliary arch* gives origin to the corrugator supercilii muscle. The nasal part of the frontal bone and the frontal process of the maxilla give origin to the orbital part of the orbicularis oculi muscle. Between these two areas the medial palpebral ligament is attached to the frontal process of the maxilla (fig. 362). The procerus muscle arises from the nasal bone near the median plane. The lower margin of the nasal bone usually presents a small notch, converted into a foramen in the fresh specimen by the lateral cartilage of the nose. It transmits the external nasal nerve. In front of the orbicularis oculi the levator labii superioris alæque nasi takes origin from the frontal process of the maxilla. More laterally, the levator labii superioris arises from the maxilla in the interval between the infra-orbital margin and the foramen of the same name.

The stout root of the canine tooth produces an elevation termed the *canine eminence*, which separates the *canine fossa* on its lateral side from the *incisive fossa* on its medial side. The levator anguli oris arises from the canine fossa, while the incisive fossa gives origin to the compressor naris muscle. Below these fossæ the anterior surface of the maxilla gives origin to the depressor septi the dilatator naris and the incisive muscle of the upper lip.

The zygomatic bone is marked opposite the junction of the infra-orbital and lateral margins of the orbit by the small *zygomaticofacial foramen* (fig. 297) which transmits the nerve of the same name and a minute artery. The foramen, which is sometimes duplicated, opens laterally and downwards. Below the foramen the zygomatic bone gives origin to the zygomaticus minor muscle, and more laterally to the zygomaticus major muscle.

THE ORBIT (figs. 299-302)

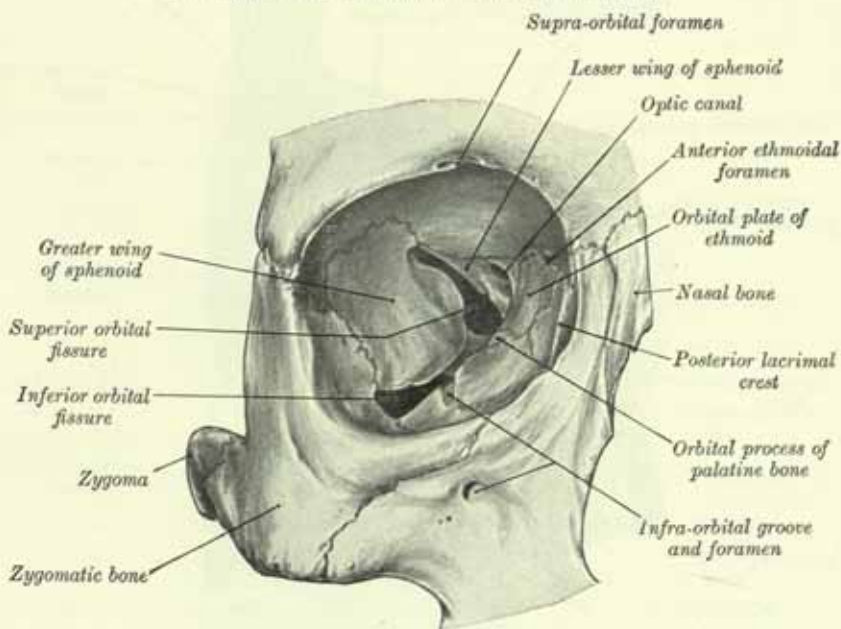
General features.—The *orbits* are a pair of roomy cavities which contain the eye-balls, their associated muscles, vessels, nerves, etc., and most of the lacrimal apparatus, together with a variable amount of soft fat. The orbital cavity is pyramidal in shape; its base is the orbital opening on the face, and its long axis is directed backwards and medially. Each orbit presents a roof, a floor, medial and lateral walls, a base or orbital opening and an apex.

The *superior wall* or *roof* is a thin, gently concave plate of bone which intervenes, throughout most of its extent, between the orbit and the part of the brain in the

anterior cranial fossa. In its anteromedial part it is separated into two laminae by the frontal sinus, which is an air-space in the bone communicating with the nasal cavity. In its anterolateral part it presents a deep hollow which lodges the orbital part of the lacrimal gland and is termed the *lacrimal fossa*. At the posterior end of the junction of the roof with the medial wall the **optic canal (optic foramen)** establishes communication between the orbit and the middle cranial fossa. It transmits the optic nerve and the ophthalmic artery. Close to the superior, medial and lower margins of the opening of the canal into the orbit a common tendinous ring is attached to the orbital walls for the origin of certain muscles of the eyeball (fig. 942).

The **medial wall** (fig. 301) is exceedingly thin, except at its most posterior part, and slopes gently downwards and laterally into the floor. Anteriorly, it presents the *lacrimal groove*, which lodges the lacrimal sac. The groove communicates below with the nasal cavity through the *nasolacrimal canal*, which is little more than 1 cm. long and transmits the nasolacrimal duct. The floor of the groove separates the orbital cavity from the nasal cavity, but behind the groove the air-containing

FIG. 299.—The right orbit, viewed from in front.



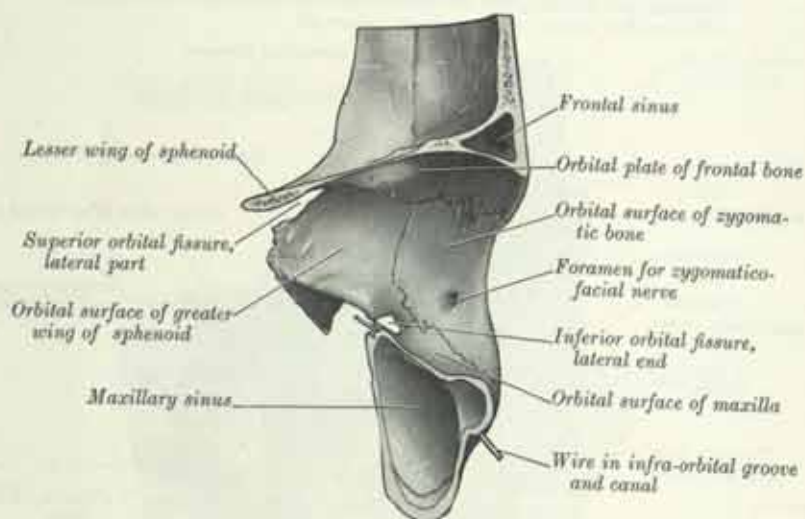
ethmoidal sinuses intervene between the two cavities. Posteriorly the medial wall is related to the anterior part of the sphenoidal sinus and forms its lateral wall.

The **inferior wall** or **floor** of the orbit (fig. 300) is relatively thin and constitutes, in most of its extent, the roof of the maxillary sinus (fig. 301). It is not quite horizontal, but faces upwards and slightly laterally. In front it is directly continuous with the lateral wall, but posteriorly the two walls are separated by the **inferior orbital fissure**. This fissure leads into the orbit from the pterygopalatine fossa posteriorly, and from the infratemporal fossa anteriorly. The maxillary nerve is the most important structure which it transmits. The lower lip of the fissure is notched by the *infra-orbital groove*, which passes forwards in the floor, sinking into it anteriorly and becoming converted into the *infra-orbital canal*. The anterior opening of the canal forms the infra-orbital foramen. The groove, canal and foramen transmit the infra-orbital nerve, which is the continuation of the maxillary nerve. Through the anterior part of the inferior orbital fissure a vein passes to connect the inferior ophthalmic vein with the veins of the pterygoid plexus in the infratemporal fossa.

The **lateral wall** (fig. 302) is the thickest of the orbital walls, especially behind, where it separates the orbit from the middle cranial fossa. In front it is interposed between the orbit and the temporal fossa. The lateral wall and the roof are continuous anteriorly, but they are separated posteriorly by the **superior orbital fissure**.

bounded above by the lesser and below by the greater wing of the sphenoid and medially by the body of that bone. The lacrimal and frontal nerves traverse the narrow, lateral part of the fissure which transmits also the meningeal branch of the lacrimal artery and the occasional orbital branch of the middle meningeal artery. The trochlear nerve is situated more medially and lies just outside the common tendinous ring. The two divisions of the oculomotor nerve, the nasociliary and the abducent nerves pass within the common tendinous ring, and therefore traverse the wider, medial part of the fissure. They may be accompanied by the superior and inferior ophthalmic veins, but the superior ophthalmic veins may accompany the trochlear nerve and the inferior ophthalmic veins may pass through the medial end of the fissure below the common tendinous ring.

FIG. 302.—The lateral wall of the left orbit, viewed from the medial side. Compare with fig. 301, which represents the opposite part of the same section of the skull.



NORMA OCCIPITALIS

The outline of the skull, as viewed from behind, is shaped like a broad arch, being convex above and on each side, and flattened below. The *lambdoid suture*, which has already been seen in part, can now be traced through its entire length. The serrations are deep and prominent above and behind, but become much less conspicuous as the suture is traced downwards and forwards. Inferiorly the lambdoid suture meets the *occipitomastoid suture* and the *parietomastoid suture* at the posteroinferior angle of the parietal bone (fig. 292). The posterior portions of the parietal bones, parietal tubera and foramina, which are visible on the *norma occipitalis*, have already been viewed from above.

The most outstanding feature of the *norma occipitalis* is the **external occipital protuberance** (fig. 304) and the ridges which lead away from it. The protuberance is situated in the lower part of the field in the median plane and may be overhanging. It can readily be identified in the living subject, as it lies at the upper end of the median furrow at the back of the neck. The *superior nuchal lines* are the ridges, often sharp in character, which pass laterally from the protuberance. They form the boundary lines between the scalp and the back of the neck, and the portions of the occipital bone below them, now seen in perspective, will be examined in the *norma basalis*. The *highest nuchal lines*, when present, are curved bony ridges, which lie about 1 cm. above the superior nuchal lines. Commencing at the upper part of the protuberance they are more arched than the superior nuchal lines.

The mastoid process and the mastoid part of the temporal bone can be seen in the inferolateral part of this aspect of the skull, but they can be examined much more satisfactorily in the *norma lateralis*.

Particular features.—The *inion* is the name given to the most salient point on the external occipital protuberance in the median plane. The lower part of the protuberance gives attachment to the upper end of the ligamentum nuchæ, and its upper part gives origin to fibres of the trapezius muscle, which arises also from the adjoining part of the *superior nuchal line*. The lateral part of the superior nuchal line (fig. 327) gives insertion to the posterior fibres of the sternomastoid and, under cover of that muscle, to fibres of the splenius capitis. The *highest nuchal line* gives attachment medially to the galea aponeurotica (epicranial aponeurosis) and laterally to the occipital belly of the occipitofrontalis muscle.

NORMA LATERALIS (fig. 303)

When the skull, minus the mandible, is examined from the side, it will be found that the anterior, superior and posterior parts have been described already in the *normæ frontalis*, *verticalis* and *occipitalis*, respectively. The central area, however, presents many important features which have not yet received consideration. It is limited above by the **temporal line**, which arches upwards and backwards from the zygomatic process of the frontal bone across the coronal suture to the parietal bone. Salient at first, it can be felt easily through the skin, but as it arches across the parietal bone it is much less distinct and is usually represented by two curved ridges, which enclose between them a smooth and often polished strip of bone. Posteriorly the upper of these two lines fades away, but the lower becomes more prominent as it curves downwards and forwards across the squamous part of the temporal bone, just above its union with the mastoid portion. This part of the line, which is often termed the *supramastoid crest*, becomes continuous with the posterior root of the zygomatic process. Throughout the whole of its extent the temporal line marks the periphery of the temporalis muscle and its covering fascia. On the parietal bone the muscle arises from the lower ridge, while the fascia is attached to the upper ridge and to the bone below.

The **temporal fossa** is the region bounded by the zygomatic arch, the temporal line and the frontal process of the zygomatic bone, and its floor gives origin to the temporalis muscle. An irregularly H-shaped arrangement of sutures can be seen in the anterior part of the fossa, the more or less horizontal limb of the H being formed by the suture between the antero-inferior part of the parietal and the upper border of the greater wing of the sphenoid bone. In this situation the frontal, the sphenoid, the parietal and the squamous part of the temporal bone closely adjoin one another (fig. 303), and a small circular area can be outlined so as to include portions of all four. This area is termed the **pterion**, and its centre—which is an important landmark for the surgeon—lies 3.5 cm. behind and 1.5 cm. above the frontozygomatic suture (fig. 304). The anterior wall of the fossa is formed by the temporal surface of the zygomatic bone, the adjoining part of the greater wing of the sphenoid and a small portion of the frontal bone. It is interposed between the fossa and the orbit. Inferiorly the fossa communicates freely with the infratemporal fossa through the gap which separates the zygomatic arch from the rest of the skull. In this situation the tendon and some fleshy fibres of the temporalis descend to reach their insertion into the mandible (p. 306).

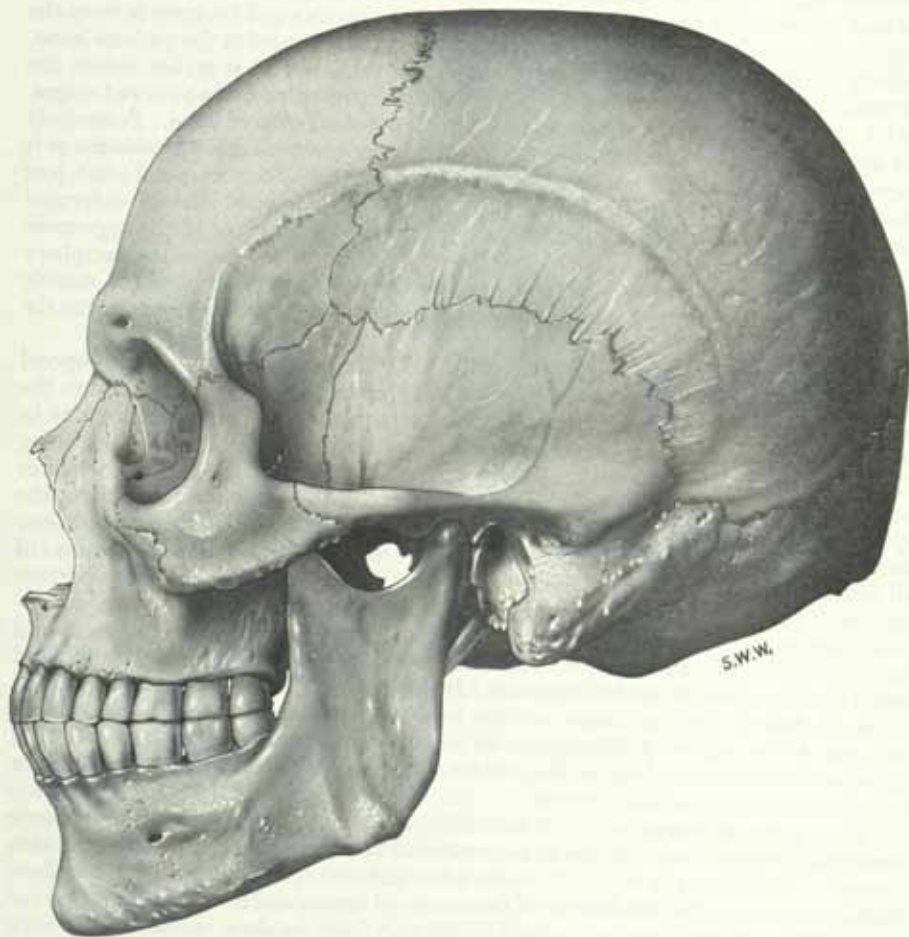
The **zygomatic arch**, which is formed by the temporal process of the zygomatic bone and the zygomatic process of the temporal bone, is easily felt through the skin where the cheek and the region of the temple meet each other. Its sharp, upper border is obscured by the attachment of the temporal fascia, and its lower border by the origin of the masseter muscle, which arises also from its deep surface. The arch stands away from the rest of the skull and is separated from it by a gap which is deeper in front than behind. Anteriorly, the arch is crossed by the zygomatico-temporal suture, which is directed obliquely downwards and backwards.

The *zygomatic process of the temporal bone*, or *zygoma*, widens posteriorly as it approaches the squamous part, and divides into an anterior and a posterior root. The *anterior root* passes medially in front of the *mandibular fossa* and becomes continuous with the smooth *articular tubercle*, which forms the anterior boundary of the fossa. The *posterior root* passes backwards, lateral to the fossa, and its upper border becomes continuous with the supramastoid crest of the temporal bone.

The **external acoustic meatus** opens immediately below the posterior part of the posterior root of the zygoma. The margins of the orifice are roughened, especially below and in front, for the attachment of the cartilaginous segment of the

meatus. The upper margin and the upper part of the posterior margin are formed by the squamous part of the temporal bone; the anterior margin, the inferior margin and the lower part of the posterior margin are formed by the *tympanic part* of the temporal bone. The squamotympanic suture can be seen without difficulty at the anterosuperior part of the opening, but the suture on the posterior wall is usually obliterated in the adult skull. Below the orifice of the meatus the tympanic plate is drawn downwards, forming a somewhat triangular roughened area. Immediately above and behind the meatus there is frequently a small depression with a bony spicule in its anterior margin (*suprameatal spine*). This lies within the area of the *suprameatal triangle*, which is bounded above by the supramastoid crest, in front by the posteriosuperior margin of the orifice of the meatus

FIG. 303.—The skull. Left lateral aspect. (*Norma lateralis*.)
Compare with Key, fig. 304.



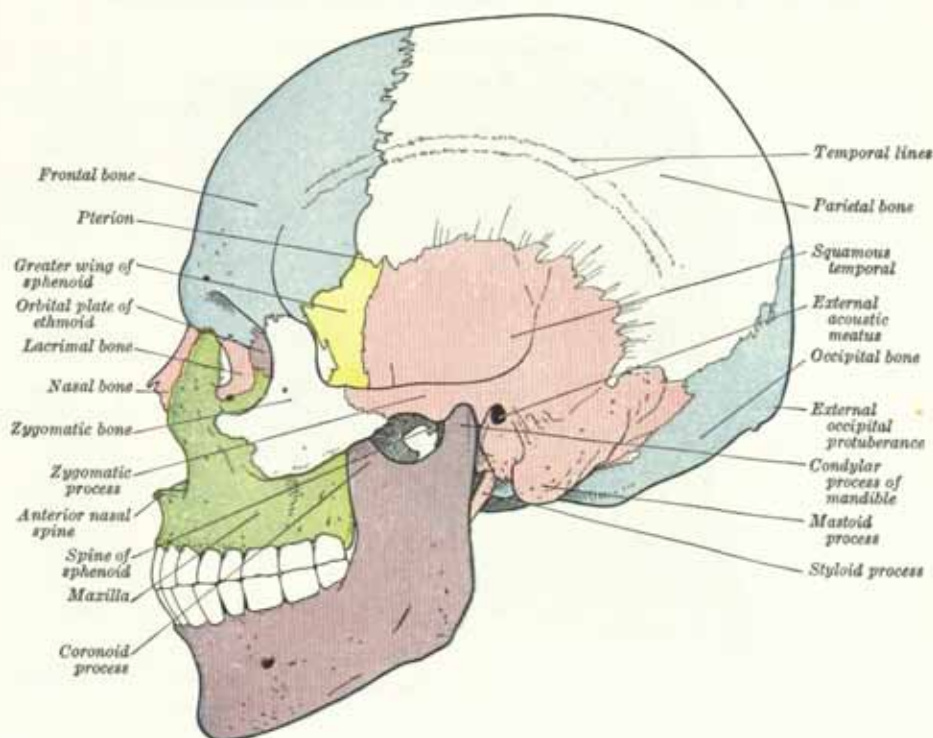
and behind by a vertical line, drawn as a tangent to the curve of the posterior margin of the meatal orifice. This triangle forms the lateral wall of the mastoid (tympanic) antrum (p. 323), which is an air-space of great importance to the surgeon and is contained in the petrous part of the temporal bone.

Behind the meatus the *norma lateralis* is formed by the **mastoid portion of the temporal bone**. Above, it is continuous with the squamous portion in front, but, behind, it possesses a free upper border, which articulates with the postero-inferior part of the parietal bone at the horizontal *parietomastoid suture*. Its posterior border is free and articulates with the squamous part of the occipital bone at the *occipitomastoid suture*. These two sutures meet each other at the lateral extremity of the lambdoid suture. The **mastoid process** (fig. 303) is a strong, nipple-shaped

projection from the lower part of the mastoid portion of the temporal bone. It lies immediately behind the external acoustic meatus, but at a lower level, and its anterior part can be felt through the skin under cover of the lobule of the auricle. The *mastoid foramen* pierces the bone above the base of the mastoid process and near, or on, the occipitomastoid suture; it transmits an important emissary vein from the sigmoid sinus.

The **styloid process** (fig. 303) is a slender, elongated projection which, although attached to the norma basalis, can be examined conveniently at this stage. It lies a short distance in front of the mastoid process but is on a deeper plane, its base being partly ensheathed by the lower margin of the tympanic plate. Directed downwards, forwards and slightly medially, its tip is usually hidden by the posterior margin of

FIG. 304.—Key to fig. 303.



NOTE: blue=frontal and occipital; pink=temporal, lacrimal and nasal; magenta=mandible and ethmoid; green=maxilla; yellow=sphenoid.

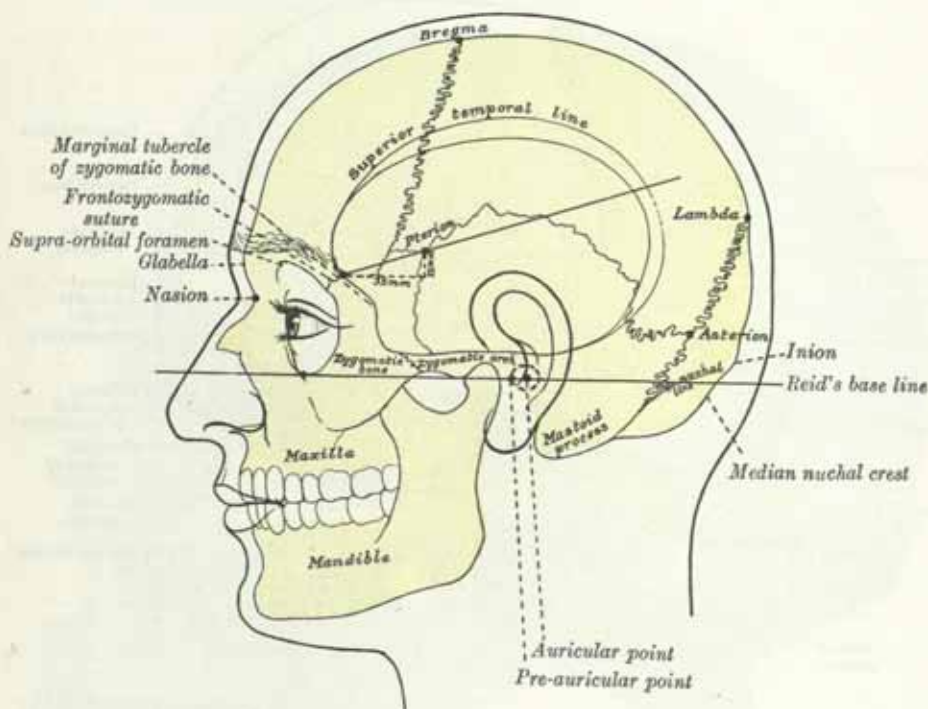
the ramus of the mandible, when that bone is in place. From its extremity the stylohyoid ligament passes downwards and forwards to the lesser cornu of the hyoid bone (p. 310), which is therefore suspended from the skull.

The **infratemporal fossa** (fig. 306) is an irregularly shaped space which lies behind the maxilla. It communicates with the temporal fossa through the gap between the zygomatic arch and the side of the skull. Medial to this gap, the roof is formed by the infratemporal surface of the greater wing of the sphenoid, and a small part of the squamous temporal. In this situation the greater wing is pierced by the foramen ovale and the foramen spinosum. The medial wall is formed by the lateral pterygoid plate. These walls are considered in detail in connexion with the norma basalis (p. 283). Behind, below and on the lateral side the fossa is freely open. The anterior and medial walls meet below but they are separated above by the *pterygopalatine fissure*, through which the infratemporal fossa communicates with the pterygopalatine fossa. The upper end of the pterygopalatine fissure is continuous with the posterior end of the *inferior orbital fissure*, which is placed between the upper part of the posterior surface of the maxilla and the greater wing of the sphenoid. This fissure connects the infratemporal fossa with the orbit (p. 273).

The **pterygopalatine fossa** is a small pyramidal space situated below the apex of the orbit. It communicates with the infratemporal fossa through the pterygopalatine fissure and with the orbit through the medial end of the inferior orbital fissure. The foramen rotundum opens on its posterior wall, and the maxillary nerve, which runs forwards and laterally from the foramen across the upper part of the fossa, is the most important of its contents.

Particular features.—The floor of the *temporal fossa* is marked by a few small vascular furrows, of which the most constant are above the external acoustic meatus and are produced by the middle temporal vessels. In the anterior wall of the fossa the *zygomaticotemporal foramen* pierces the temporal surface of the zygomatic bone in an upward and backward direction. It transmits the zygomaticotemporal nerve and a minute artery. In addition to the tendon of the temporalis muscle, the deep temporal

FIG. 305.—A side view of the head, showing the surface relations of the bones.



vessels and nerves traverse the gap between the zygomatic arch and the rest of the skull and ascend into the temporal fossa.

As the anterior root of the zygoma springs from the process, it is marked by a small tubercle often termed the *tubercle of the root of the zygoma*. It gives attachment to fibres of the lateral ligament (fig. 485) of the temporomandibular joint and can be felt through the skin immediately in front of the head of the mandible. Behind the mandibular fossa a small downward projection from the posterior root of the zygoma (sometimes termed the *post-glenoid tubercle*) meets the tympanic plate at the antero-superior part of the orifice of the external acoustic meatus (fig. 334) and its anterior aspect takes a small part in the formation of the mandibular fossa.

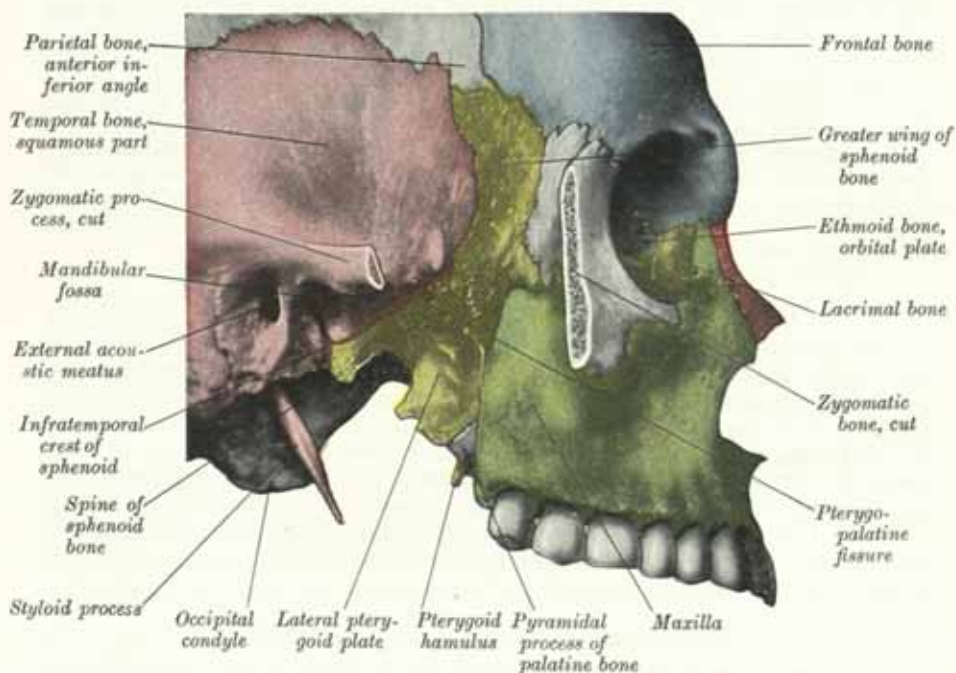
The posterior part of the lateral surface of the *mastoid process* and its rounded apex are roughened by the insertions of the sternomastoid, splenius capitis and longissimus capitis muscles, in that order from before backwards. In front of, and parallel to, this roughened area, the partially obliterated remains of the squamomastoid suture may be visible. From the position of the suture it will be obvious that the floor of the suprameatal triangle, and therefore the lateral wall of the mastoid antrum, is formed by the squamous part of the temporal bone. The tympanomastoid fissure is placed on the anterior aspect of the base of the process. The outer opening of the mastoid canaliculus (p. 325), which transmits the auricular branch of the vagus nerve, is placed between the lips of the fissure.

The *styloid process* is covered on its lateral aspect by the parotid gland and intervenes between that structure and the internal jugular vein. It gives origin to three

muscles. The stylohyoid arises by a delicate tendon from its posterior aspect, nearer to the base than to the tip; the styloglossus from the tip and the adjacent part of the anterior aspect; and the stylopharyngeus from the medial aspect of the base. The stylomandibular ligament is attached to the lateral aspect of the process in its lower part and the stylohyoid ligament to its tip. Behind the base of the process the facial nerve emerges from the stylomastoid foramen and passes forwards lateral to the process in the substance of the parotid gland.

The **infratemporal fossa** (fig. 306) contains the lower part of the temporalis muscle as it passes to be inserted into the coronoid process. The maxillary artery and its branches and the pterygoid plexus of veins lie deep to the temporalis and usually on the lateral surface of the lower head of the lateral pterygoid muscle. The deepest part of the fossa is occupied by the medial pterygoid muscle, the mandibular nerve and the chorda tympani. The mandibular nerve enters the fossa through the foramen ovale in its roof and breaks up into its terminal branches under cover of the lateral pterygoid muscle. Its branches traverse the fossa and most of them leave it to gain

FIG. 306.—The right infratemporal fossa.



Blue = frontal bone. Yellow = sphenoid and lacrimal bones. Pink = temporal and nasal bones. Green = maxilla. The parts shown of the parietal, zygomatic, ethmoid and palatine bones are uncoloured.

other regions. The chorda tympani enters the fossa on the medial side of the spine of the sphenoid and runs downwards and forwards to join the lingual nerve. The maxillary nerve appears at the upper part of the fossa as it passes between the upper end of the pterygopalatine fossa and the inferior orbital fissure. The *anterior wall* of the fossa is pierced by two or three small foramina which transmit the posterior superior alveolar (dental) vessels and nerves. It is limited below by the alveolar part of the maxilla in the region of the molar teeth, and in this situation a horizontal strip of the bone is closely covered with the mucous membrane of the gum. Immediately above this strip the bone gives origin to the upper fibres of the buccinator muscle, which extends backwards behind the last molar tooth on to the tuberosity of the maxilla. The medial wall of the fossa, formed by the lateral pterygoid plate is completed below and in front by the pyramidal process (tubercle) of the palatine bone, which is wedged in between the tuberosity of the maxilla and the lateral pterygoid plate. The superficial head of the medial pterygoid muscle arises from this surface of the pyramidal process and the adjoining part of the maxillary tuberosity.

The **pterygopalatine fissure** is a triangular interval formed by the divergence of the maxilla from the pterygoid process of the sphenoid bone. It transmits the terminal part of the maxillary artery to the pterygopalatine fossa, and its uppermost part gives passage to the maxillary nerve, which appears for a very short part of its course

in the upper part of the infratemporal fossa before it enters the inferior orbital fissure. The **inferior orbital fissure** leads forwards into the orbit (p. 273).

The **pterygopalatine fossa** (fig. 306) communicates *above* with the orbit through the medial (or posterior) part of the inferior orbital fissure and it is closed *inferiorly* where the lower part of the lateral surface of the perpendicular plate of the palatine bone meets the postero-inferior part of the medial surface of the maxilla. It is bounded *behind* by the root of the pterygoid process and the adjoining part of the anterior surface of the greater wing of the sphenoid; *medially*, by the upper part of the perpendicular plate of the palatine bone with its orbital and sphenoidal processes; *in front*, by the medial portion of the upper part of the posterior surface of the maxilla. On the *lateral side* it communicates with the infratemporal fossa through the pterygopalatine fissure. The most important contents of the fossa are the maxillary nerve, the pterygopalatine ganglion and the terminal part of the maxillary artery. The maxillary nerve enters the fossa through the foramen rotundum and passes forwards and laterally to the posterior end of the infraorbital groove in the floor of the orbit. Below and medial to the foramen rotundum the pterygoid canal transmits the nerve (and artery) of the same name from the lower part of the anterior wall of the foramen lacerum to the pterygopalatine ganglion and inferomedially the palatinovaginal canal transmits the pharyngeal nerve (and artery) from the ganglion to the roof of the pharynx. A fourth foramen is placed on the medial wall and is termed the *sphenopalatine foramen* (fig. 316). It is bounded above by the body of the sphenoid, in front by the orbital process of the palatine bone, behind by the sphenoidal process and below by the upper border of the perpendicular plate. It transmits to the nasal cavity the nasopalatine (long sphenopalatine) nerve and the accompanying vessels. The fifth foramen is placed inferiorly at the junction of the anterior and posterior walls, and leads into the *greater palatine canal*. Bounded antero-laterally by the maxilla and posteromedially by the perpendicular plate of the palatine bone, this canal transmits the greater and lesser palatine nerves and vessels, which appear at the greater and lesser palatine foramina on the bony palate (*vide infra*).

NORMA BASALIS (figs. 307-310)

The lower surface of the base of the skull is bounded in front by the incisor teeth of the maxillæ, behind by the superior nuchal lines of the occipital bone, and laterally by the other teeth, the zygomatic arch and its posterior root, and the mastoid process. It is very irregular and, unlike the internal surface, shows no natural subdivision into regions suitable for descriptive purposes. It is, however, useful to divide the area into anterior, middle and posterior parts. The anterior part, which is formed by the hard palate and the alveolar arches is on a lower level than the part behind. The remainder of the surface is divided, in an arbitrary manner, into a middle and a posterior part by a transverse line drawn through the anterior margin of the foramen magnum.

THE ANTERIOR PART OF THE NORMA BASALIS

The **bony palate** (fig. 309) lies within the arch formed by the teeth of the maxillæ and the alveolar processes. It is formed by the palatine processes of the maxillæ and the horizontal plates of the palatine bones, which are separated from one another by a cruciform suture, made up of the intermaxillary, interpalatine and palatamaxillary sutures. Owing partly to the downward projection of the alveolar arches, the palate is arched both from before backwards and from side to side. The depth and the breadth of the palatine vault are subject to considerable variation but are always greatest in the region of the molar teeth. A deep fossa, termed the *incisive fossa*, lies in the median plane anteriorly. The *lateral incisive foramina*, which lead into the incisive canals and so to the floor of the nasal cavity (p. 300), are situated in its lateral walls; the *median incisive foramina*, which are present in some skulls, open on its anterior and posterior walls. The *greater palatine foramen*, which is the lower orifice of the canal of the same name, opens close to the lateral border of the palate immediately behind the palatamaxillary suture (fig. 309). A vascular groove, deep behind and becoming shallower in front, leads forwards away from the foramen. The *lesser palatine foramina*, usually two in number, are situated behind the greater foramen. They pierce the *pyramidal process of the palatine bone*, which projects backwards and laterally from the posterolateral corner of the bony palate and becomes wedged into the notch between the lower ends of the two pterygoid plates. The vault of the bony palate is uneven, pierced by numerous small foramina and marked by depressions for the palatine glands. Near the posterior border it

presents a slightly curved ridge of variable prominence, termed the *palatine crest*, which commences behind the greater palatine foramen and runs medially. The posterior border of the bony palate is free and projects backwards in the median plane to form the *posterior nasal spine*.

The *alveolar arch* provides sixteen sockets for the roots of the teeth. These sockets vary in size and depth and are single or subdivided by septa according to the teeth which they contain.

Particular features.—The *lateral incisive foramen* transmits the terminal branches of the greater palatine vessels and the nasopalatine nerve. When median incisive foramina are present the left nasopalatine nerve passes through the anterior and the right through the posterior foramen. The lateral incisive foramina are placed in the line of fusion of the os incisivum (premaxilla) with the maxilla proper, and represent a primitive communication between the mouth and the nose. In young skulls the suture line between the os incisivum and the maxilla may be visible, extending from the posterior part of the incisive fossa to the septum between the sockets of the lateral incisor and canine teeth. The *greater palatine foramen* transmits the greater palatine nerve and vessels, and the vessels groove the lateral part of the palate as they run forwards to the incisive fossa. The *lesser palatine foramina*, usually two, sometimes one and occasionally three in number, perforate the inferior and medial aspects of the pyramidal process of the palatine bone; they transmit the lesser palatine nerves. The *palatine crest*, which commences on the tubercle and extends on to the horizontal plate of the palatine bone, gives attachment to part of the tendon of the tensor veli palatini muscle. The free posterior border of the bony palate gives attachment to the palatine aponeurosis and the posterior nasal spine to the musculus uvulæ.

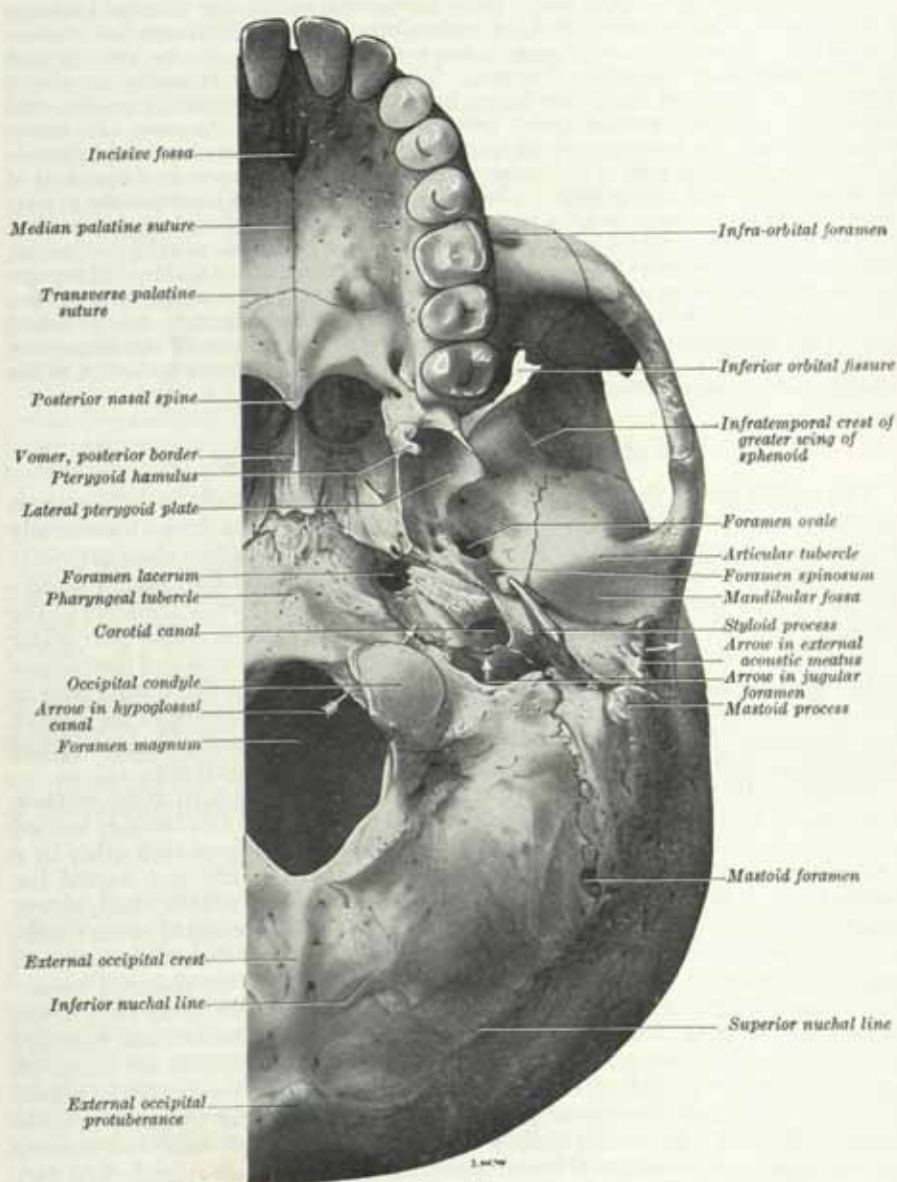
THE MIDDLE PART OF THE NORMA BASALIS

The middle part of the external surface of the base of the skull (fig. 307) extends from the posterior border of the bony palate to an arbitrary line drawn transversely through the anterior margin of the foramen magnum. In the median plane anteriorly the *posterior border of the vomer* separates the two *posterior nasal apertures*. Immediately behind the vomer the posterior part of the inferior surface of the body of the sphenoid is directly continuous with the inferior surface of the *basilar part of the occipital bone*, which forms a broad bar of bone extending backwards and downwards to the foramen magnum. It is convex from side to side and wider behind than in front. A short distance in front of the foramen magnum it is marked in the median plane by a small elevation, termed the *pharyngeal tubercle*, which gives attachment to the highest fibres of the superior constrictor muscle of the pharynx.

Behind the third molar tooth the **pterygoid process** descends from the junction of the greater wing and the body of the sphenoid bone. It has two laminae, termed the medial and lateral pterygoid plates, which are separated from each other by a V-shaped interval, directed backwards and somewhat laterally and named the *pterygoid fossa*. Anteriorly the two pterygoid plates are fused to each other, except inferiorly, where they are separated by a narrow gap which is occupied in the articulated skull by the *pyramidal process* of the palatine bone, and the suture lines can usually be identified. On the medial side they articulate with the posterior border of the perpendicular plate of the palatine bone in front, and form with it the flattened area of bone which lies in the lateral wall of the posterior nasal aperture and nasal part of the pharynx. On the lateral side the fused laminae are separated from the posterior surface of the maxilla in front by the pterygopalatine fissure (fig. 306). The *medial pterygoid plate* is the narrower of the two and projects directly backwards. Its medial surface is covered in the recent state with mucous membrane and forms the lateral boundary of the posterior nasal aperture and part of the lateral wall of the nasal part of the pharynx. The posterior border of the medial pterygoid plate is thin and sharp, and presents a small projection about its midpoint. Above this projection the border is curved and is attached to the pharyngeal end of the auditory (pharyngotympanic) tube. At its upper end the border divides to enclose the shallow, *scaphoid fossa* (fig. 310); below, it projects beyond the rest of the plate as the slender *pterygoid hamulus*. This process curves downwards and laterally and is grooved anteriorly at its root by the tendon of the tensor veli palatini muscle. The *lateral pterygoid plate* projects backwards and laterally and its lateral surface forms the medial wall of the infratemporal fossa. Superiorly it is continuous with the *infratemporal surface of the greater wing of the*

sphenoid, which forms the anterior part of the roof of the infratemporal fossa. This surface of the greater wing is directed downwards and, sometimes, slightly to the lateral side. It is roughly pentagonal; its anterior margin forms the posterolateral border of the inferior orbital fissure; and in front and to the lateral side it is limited by the infratemporal crest. Laterally it articulates with the squama of the temporal

FIG. 307.—The lower surface of the left half of the base of the skull.
(Norma basalis.)

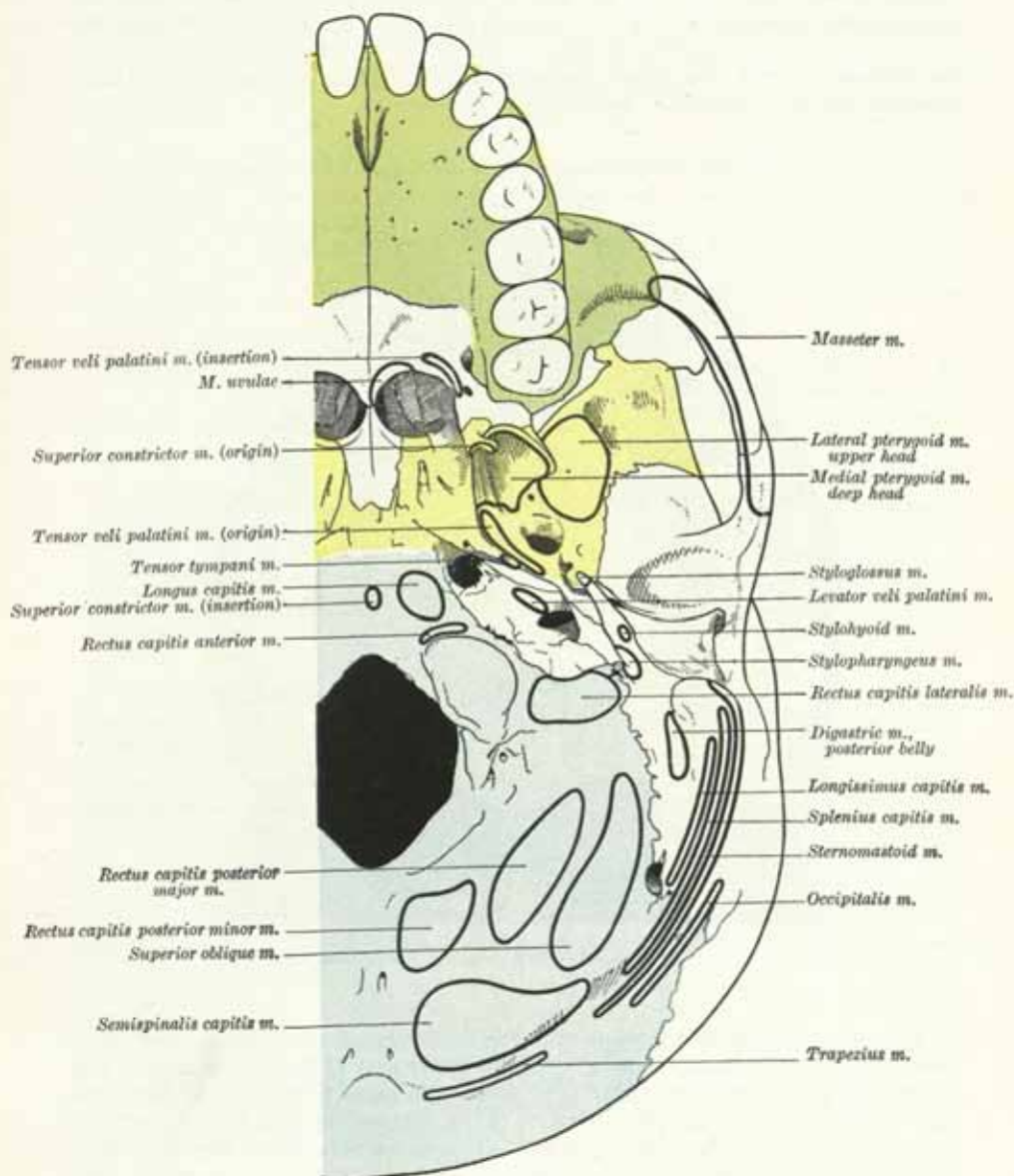


bone; medially it is continuous with the root of the pterygoid process and the side of the body of the sphenoid; and posteromedially it articulates with the petrous part of the temporal bone.

Two important foramina open on the infratemporal surface of the greater wing of the sphenoid. The **foramen ovale**, irregularly oval in outline, lies close to the posterior border and posterolateral to the upper end of the posterior margin of the lateral pterygoid plate. It transmits the mandibular division of the trigeminal nerve. Posterior and slightly lateral to the foramen ovale the **foramen spinosum** pierces the greater wing and transmits the middle meningeal artery to the middle cranial

fossa. It is much smaller than the foramen ovale and is circular in outline. Immediately posterolateral to the foramen spinosum the posterolateral angle of this surface of the greater wing forms an irregular downward projection, termed the *spine of the sphenoid*. The medial surface of the spine is flattened, and together with the adjoining part of the posterior border of the greater wing forms the anterolateral border

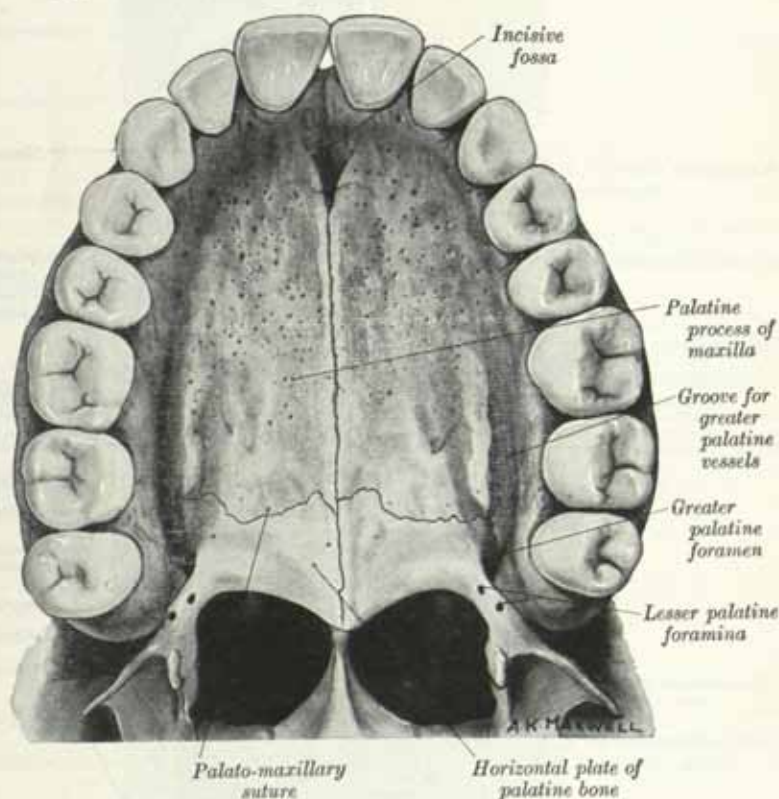
FIG. 308.—Key to fig. 307.



of a groove which is completed on the posteromedial side by the petrous part of the temporal bone. This groove lodges the cartilaginous part of the auditory tube, and leads backwards into the canal for the tube in the petrous part of the temporal bone and forwards to the upper part of the posterior border of the medial pterygoid plate. In the roof of the groove the posterior border of the greater wing and the anterior border of the petrous temporal come into apposition with each other. It will be apparent that immediately below the skull the mandibular nerve and the middle meningeal artery must be related to the anterolateral aspect of the auditory tube.

Behind and medial to the groove for the tube the *inferior surface of the petrous temporal* occupies the interval between the infratemporal surface of the greater wing of the sphenoid and the basilar part of the occipital bone. The anterior part of this surface is rough and uneven, and its apex is separated from the posterolateral part of the body of the sphenoid by an irregular bony canal, termed the *foramen lacerum*. Behind this rough area a large and approximately circular foramen leads upwards into the bone. It is the lower opening of the *carotid canal*, which is traversed by the internal carotid artery. Within the bone the canal turns forwards and medially and opens on the posterior wall of the foramen lacerum. After passing through the canal the artery turns upwards to gain the interior of the skull. The lower part of the foramen lacerum is occupied in the recent state by fibrocartilage, and no large structure enters or leaves the skull through this opening.

FIG. 309.—The bony palate and the alveolar arch. Inferior aspect.



Lateral to the base of the spine of the sphenoid the *squamotympanic fissure* runs laterally and slightly backwards between the upper part of the tympanic plate and the floor of the mandibular fossa. The fissure can usually be traced to the upper part of the anterior margin of the orifice of the external acoustic meatus, but it is sometimes obliterated near its lateral end. The *mandibular fossa* is deeply concave from before backwards and gently concave from side to side, and is wider at its lateral than at its medial end. It lodges the head of the mandible when the mouth is closed. Anteriorly the articular surface passes on to a transverse rounded elevation, termed the *articular tubercle*, which is continuous laterally with the anterior root of the zygoma. In front it becomes continuous with the part of the squamous temporal which lies in the roof of the infratemporal fossa. Behind the squamo-tympanic fissure the *tympanic part of the temporal bone* separates the mandibular fossa from the external acoustic meatus. This part of the temporal bone is roughly triangular in outline, the apex being situated at the medial end of the squamo-tympanic fissure close to the root of the spine of the sphenoid. Its lower border is free and skirts the anterolateral margin of the lower opening of the carotid

canal, extending backwards and laterally to reach the root of the styloid process. There it forms the *sheath of the styloid process*, which is longer and more apparent on the lateral than on the medial side. At its lateral margin the tympanic part is fused with the rest of the temporal bone below and behind and is free above, where it forms the anterior border of the orifice of the external acoustic meatus.

Particular features.—The upper border of the *vomer*, which is applied to the inferior surface of the body of the sphenoid, is expanded into an *ala* on each side (fig. 358), and the groove between the alæ receives the *rostrum of the sphenoid*. The lateral border of each ala comes into relation with a thin lamella which projects medially from the root of the medial pterygoid plate and is termed the *vaginal process*. The two may come merely into contact or the edge of the ala may extend into the narrow interval between the body of the sphenoid above and the vaginal process below. The inferior surface of the vaginal process is marked by an anteroposterior groove, which is converted into a canal anteriorly by the upper surface of the sphenoidal process of the palatine bone. This canal is termed the *palatino-vaginal canal* and opens anteriorly through the posterior wall of the pterygopalatine fossa. It transmits the pharyngeal branch of the pterygopalatine ganglion and a minute pharyngeal branch from the third part of the maxillary artery. A second canal may be present in this situation on the medial side of the palatinovaginal canal. It lies between the ala of the vomer and the upper surface of the vaginal process and is termed the *vomerovaginal canal*. When present it leads forwards into the anterior end of the palatinovaginal canal.

In front of the pharyngeal tubercle the *inferior surface of the basilar part of the occipital bone* is intimately related to the roof of the nasal pharynx and the pharyngeal tonsil. Lateral to the tubercle the bone receives the insertion of the longus capitis muscle, and the area extends forwards on each side beyond the tubercle. Behind the longus capitis the rectus capitis anterior is inserted into the bone in front of the occipital condyle and medial to the outer opening of the hypoglossal (anterior condylar) canal.

At the upper part of the posterior border of the **medial pterygoid plate** the *scaphoid fossa* gives origin to the anterior fibres of the tensor veli palatini muscle, which descends along the lateral surface and posterior border of the plate to reach the *hamulus*. The tendon of the muscle twists medially round the lateral and anterior aspects of the process to gain the soft palate. The posterior border of the medial pterygoid plate, notched above by the auditory tube (p. 283), gives attachment to the pharyngobasilar fascia. Its lower part and the posterior aspect of the hamulus give origin to the highest fibres of the superior constrictor muscle of the pharynx, which curve upwards and medially to be inserted into the pharyngeal tubercle. The tip of the hamulus gives attachment to the pterygomandibular raphe. At its upper end the posterior border of the medial pterygoid plate is marked by a small tubercle, which lies on the medial side of the scaphoid fossa. This tubercle projects backwards below the posterior opening of the *pterygoid canal*, which leads forwards to open on the posterior wall of the pterygopalatine fossa. It transmits the nerve and vessels of the pterygoid canal and lies in the line of fusion of the pterygoid process and greater wing with the body of the sphenoid bone.

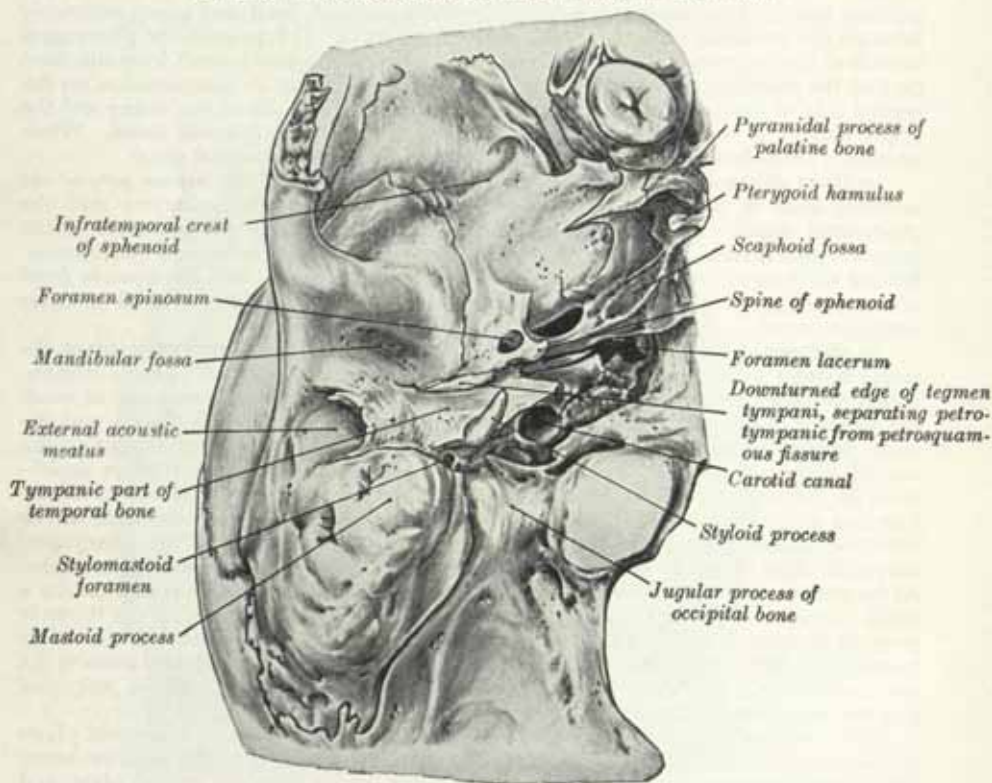
The *pterygoid fossa* lies between the opposed surfaces of the two pterygoid plates and is completed below and in front by the pyramidal process of the palatine bone. The **lateral pterygoid plate** (fig. 306) is a wider lamina than the medial plate, and its irregular posterior border may present a backward projection, termed the *pterygo-spinous process*, which is connected by a ligament (sometimes ossified) to the spine of the sphenoid. The lateral surface, which is the rougher of the two, gives origin to the lower head of the lateral pterygoid muscle; the medial surface gives origin to the deep head of the medial pterygoid muscle. The lateral aspect of the *pyramidal process of the palatine bone*, which appears between the tuberosity of the maxilla and the lower part of the lateral pterygoid plate, gives origin to some fibres of the superficial head of the medial pterygoid muscle.

The *infratemporal surface of the greater wing of the sphenoid* gives origin to the upper head of the lateral pterygoid muscle, and is crossed by the deep temporal and the masseteric nerves, which run between the muscle and the bone. In addition to the mandibular nerve the **foramen ovale** transmits the accessory meningeal artery. Its posterior border is thin and sharp and gives origin to fibres of the tensor veli palatini muscle, which intervenes between the mandibular nerve and the auditory tube. The **foramen spinosum** transmits the small meningeal branch of the mandibular nerve in addition to the middle meningeal artery. In the interval between the foramen ovale and the scaphoid fossa the bone sometimes presents a small foramen, often termed the *emissary sphenoidal foramen*, which transmits an emissary vein from the cavernous sinus. The *spine of the sphenoid*, which varies greatly in size, and may be sharply pointed or may be blunt at its extremity, gives attachment to the sphenomandibular ligament. It is related laterally to the auriculotemporal nerve and medially to the

chorda tympani—by which its medial aspect is sometimes grooved—and to the auditory tube. Anteriorly it gives origin to the most posterior fibres of the tensor veli palatini muscle. The groove for the tube varies in width and depth and its roof is occasionally completed by membrane. The lateral or sphenoidal wall of the groove gives origin, posteriorly to fibres of the tensor tympani muscle.

The lateral part of the rough inferior surface of the petrous part of the temporal bone gives origin to the levator veli palatini muscle. The **foramen lacerum** is bounded in front by the posterolateral part of the body of the sphenoid and the adjoining roots of the pterygoid process and greater wing; behind and laterally by the apex of the petrous part of the temporal bone; and medially by the basilar part of the occipital bone. It forms a canal nearly 1 cm. long, but no large structure passes through its whole length. The anterior orifice of the carotid canal opens on its posterior wall, and the vessel with its plexus of veins and its sympathetic plexus

FIG. 310.—A portion of the norma basalis of the right side.



ascends through the upper end of the canal. In the foramen the deep petrosal nerve from the carotid sympathetic plexus is joined by the greater petrosal nerve to form the nerve of the pterygoid canal, and this canal opens on the lower part of the anterior wall. Meningeal branches of the ascending pharyngeal artery and emissary veins from the cavernous sinus traverse the whole length of the foramen. The cartilage which fills its lower part is a remnant of the primitive chondrocranium.

The floor of the *mandibular fossa* is very thin and corresponds to the most lateral part of the floor of the middle cranial fossa. It is covered in the recent state by white fibrous tissue (p. 458). The *tubercle of the root of the zygoma* gives attachment to the lateral ligament of the temporomandibular joint. A thin edge of bone may be visible in the depths of the medial end of the *squamotympanic fissure*. It is the lower border of the down-turned lateral portion of the tegmen tympani and therefore is a part of the petrous temporal. It divides the upper part of the squamotympanic fissure into a petrotympanic and a petrosquamous fissure. Through the petrotympanic fissure the chorda tympani travels in its anterior canaliculus, as it passes downwards and forwards from the tympanic cavity. The anterior tympanic artery from the maxillary artery also traverses the petrotympanic fissure.

The **tympanic part of the temporal bone** (fig. 310) is separated from the capsule of the temporomandibular joint by a portion of the parotid gland, which is intimately related to the auriculotemporal nerve. It is thinnest near the centre of this surface

and is occasionally deficient in this situation (p. 327). Its grooved upper aspect forms the anterior wall, the floor and the lower part of the posterior wall of the external acoustic meatus. Except where it ensheathes the styloid process its posterior surface is fused with the petromastoid part of the bone.

THE POSTERIOR PART OF THE NORMA BASALIS (fig. 307)

The median portion of the posterior subdivision of the external surface of the base of the skull is occupied in front by the **foramen magnum**, which leads into the posterior cranial fossa. The foramen is oval in shape and its anteroposterior measurement exceeds its transverse. The curve of its margin is wider behind than in front. It transmits a large number of structures of which the most important is the lower end of the brain-stem. Anteriorly the margin of the foramen magnum is overlapped slightly on each side by the *occipital condyle*, which projects downwards to articulate with the superior articular facet on the lateral mass of the atlas. Oval in outline, the condyle is placed obliquely so that its anterior end is nearer the median plane than its posterior end. It shows a pronounced convexity from before backwards and a gentle convexity from side to side. The medial aspect is roughened for ligamentous attachments. Above the anterior part of the condyle the occipital bone is pierced by the *hypoglossal (anterior condylar) canal*, which runs laterally and slightly forwards from the posterior cranial fossa and transmits the hypoglossal nerve.

A depression of variable depth marks the occipital bone behind the condyle. It is termed the *condylar fossa*, and may be pierced by the *condylar canal*, which when present, transmits an emissary vein from the sigmoid sinus. Lateral to the condyle the *jugal process of the occipital bone* articulates with the petrous temporal. The anterior border of the process is free and forms the posterior boundary of the **jugal foramen**. This large foramen lies between the occipital bone and the jugular fossa of the petrous temporal and is placed at the posterior end of the petro-occipital suture. In front it is separated from the lower orifice of the carotid canal by a raised ridge of bone, and on its lateral side it is related to the medial aspect of the sheath of the styloid process. Medially it is separated from the hypoglossal canal by a thin bar of bone. The foramen is usually larger on the right side of the skull and its long axis is directed forwards and medially. The anterior part of the foramen transmits the inferior petrosal sinus; its intermediate part, the glossopharyngeal, vagus and accessory nerves; and its posterior part the internal jugular vein. When the superior bulb of the internal jugular vein is well developed the *jugal fossa of the temporal bone* is hollowed out in an upward and lateral direction to accommodate it.

The *styloid process* has been described already (p. 279). Posterior to its root the *stylomastoid foramen* transmits the facial nerve. Behind and lateral to the foramen the tip of the *mastoid process* projects downwards and forwards, and forms the lateral wall of the *mastoid notch*, from which the posterior belly of the digastric muscle takes origin. Medial to the notch this part of the temporal bone may be grooved by the occipital artery.

In the median plane behind the foramen magnum the squamous part of the occipital bone presents the *external occipital crest*, which gives attachment to the upper end of the ligamentum nuchæ. It terminates behind at the external occipital protuberance. Near its midpoint the *inferior nuchal line* begins and curves backwards and laterally. It is nearly parallel to the *superior nuchal line*, which extends in the same direction from the external occipital protuberance and may be raised into a distinct crest in its medial part.

Particular features.—The **foramen magnum** provides a wide communication between the posterior cranial fossa and the vertebral canal. Anteriorly it transmits the apical ligament of the dens and the membrana tectoria, both of which gain attachment to the upper surface of the basilar part of the occipital bone. Its wider, posterior part transmits the lower end of the medulla oblongata and the meninges. In the subarachnoid space the spinal roots of the accessory nerves, and the vertebral arteries, with their plexuses of sympathetic nerves, ascend to gain the interior of the cranium, the posterior spinal arteries descend, one on each posterolateral aspect of the brain stem, and the anterior spinal artery descends on the front of the brain stem in the median plane. In addition, the lower parts of the tonsils of the cerebellum may project into the foramen on each side of the medulla oblongata. The *anterior margin*

of the foramen gives attachment to the anterior atlanto-occipital membrane, which is continuous on each side with the capsular ligament of the atlanto-occipital joint. The *posterior margin* gives attachment to the posterior atlanto-occipital membrane, and the roughened medial aspect of the *condyle* to the alar ligament.

In addition to the hypoglossal nerve the *hypoglossal canal* transmits a meningeal branch of the ascending pharyngeal artery and a small emissary vein from the basilar plexus. Not uncommonly the canal is divided into two parts by a spicule of bone, a variation which is in keeping with the composite origin of the hypoglossal nerve (p. 1137). The inferior surface of the jugular process of the occipital bone provides insertion for the rectus capitis lateralis muscle.

The **jugular foramen** (fig. 307) is directed upwards, medially and backwards, and on the external surface of the base of the skull its apparent size is increased owing to the presence of the jugular fossa of the temporal bone on its lateral side. The floor of the fossa separates the superior bulb of the internal jugular vein from the tympanic cavity, and its lateral wall is pierced by a minute canal, termed the *mastoid canaliculus*, which transmits the auricular branch of the vagus nerve. Passing laterally through the bone this nerve comes into intimate relationship with the facial canal and finally emerges in the line of the tympanomastoid suture. It is extra-cranial at birth but becomes surrounded by bone as the tympanic plate and the mastoid process develop. On or near the ridge between the jugular fossa and the orifice of the carotid canal, the *canaliculus for the tympanic nerve* pierces the bone to transmit the tympanic nerve from the glossopharyngeal nerve to the middle ear. On the upper boundary of the jugular foramen near its medial end, there is a small notch—more easily identified on the internal surface—which lodges the inferior ganglion of the glossopharyngeal nerve. The orifice of the *cochlear canaliculus* (p. 324) lies at the apex of the notch, the projecting edges of which may reach the occipital bone and divide the foramen into three parts.

The *stylomastoid foramen* lies behind the root of the styloid process and at the anterior end of the mastoid notch. As the facial nerve emerges from the foramen it is in close proximity to the posterior belly of the digastric, which it supplies before entering the parotid gland. In addition to the facial nerve the foramen transmits the stylomastoid branch of the posterior auricular artery. A vascular groove crosses the inferior aspect of the posterior part of the temporal bone medial to the mastoid notch. It is caused by the occipital artery, and its absence indicates that the vessel lay at a lower level than usual and between the splenius capitis and longissimus capitis instead of deep to both muscles.

The area below the *inferior nuchal line* gives insertion medially to the rectus capitis posterior minor, and laterally to the rectus capitis posterior major (fig. 308). The interval between the inferior and the superior nuchal lines provides insertion medially for the semispinalis capitis and laterally for the obliquus superior. In its medial part the *superior nuchal line* gives origin to the highest fibres of the trapezius muscle; in its lateral part it gives insertion to fibres of the sternomastoid and, more anteriorly, splenius capitis.

THE INTERIOR OF THE SKULL

The **cranial cavity** contains the brain and its membranes and their blood-vessels. Its walls are formed by the frontal, parietal, sphenoid, temporal and occipital bones and, to a very small extent, by the ethmoid bone. They are lined with a fibrous membrane, termed the *endocranium*, which is the outer layer of the dura mater. It passes through the various foramina which lead to the exterior, and becomes continuous with the periosteum on the outer surfaces of the bones of the skull, often termed the *pericranium*. Both these fibrous membranes are continuous with the sutural ligaments, which occupy the narrow interosseous intervals at the sutures.

The walls of the cranial cavity vary in thickness in different skulls and in different parts of the same skull; but they tend to be thinner in situations where they are well covered with muscles externally, e.g. the temporal and posterior cranial fossae. Most of the cranial bones consist of an *outer* and an *inner table*, formed of compact substance and separated from each other by the *diploë*, which consists of spongy substance containing red bone marrow in its interstices. Many of the bones are so thin that the two tables are continuous, e.g. the vomer, pterygoid plates, etc. The inner table is thinner and more brittle than the outer table, which is often surprisingly resilient.

Although the skull tends to be thicker in primitive than in higher races no relationship exists between thickness of skull and mental capacity, and in all races the bones of the skull are thinner in women and children than in men.

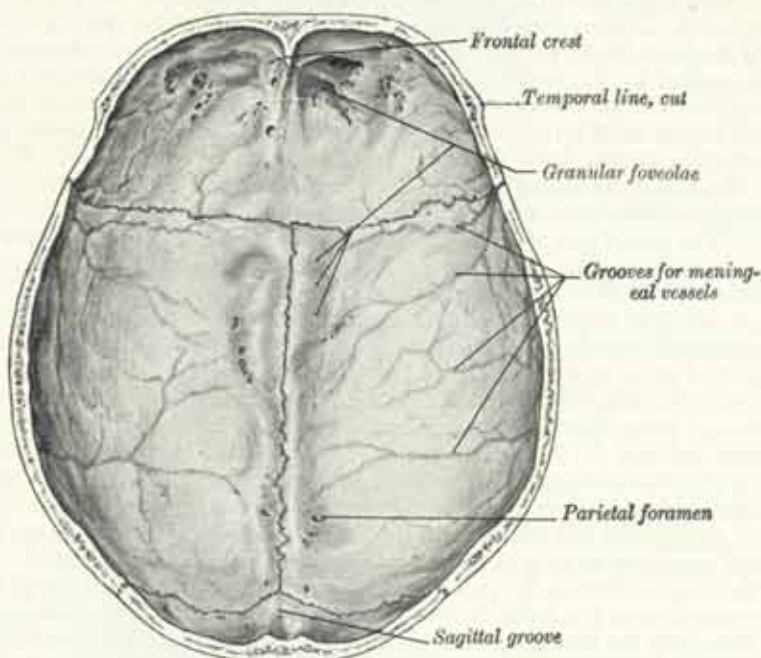
The interior of the skull is described in two sections: (1) the internal surface of the skull-cap; and (2) the internal surface of the base of the skull.

THE INTERNAL SURFACE OF THE SKULL-CAP (fig. 311)

The skull-cap comprises most of the frontal and parietal bones and the uppermost portion of the squamous part of the occipital bone. It is marked, therefore, by the coronal, sagittal and lambdoid sutures, but they may or may not be visible for the cranial sutures tend to become obliterated in old age and the *process commences on the cerebral surface*. The skull-cap is deeply concave in all directions and presents numerous vascular furrows and other markings.

Anteriorly, in the median plane, the upper end of the *frontal crest* projects backwards. It gives attachment to the falx cerebri and is grooved by the commencement of the *sagittal sulcus*. This sulcus lodges the superior sagittal sinus, and widens progressively as it runs backwards in the median plane along the sagittal suture. On each side of the sagittal sulcus the bone presents a number of irregular depressions,

FIG. 311.—The internal surface of the skull-cap.



termed *granular foveolae*. They are more numerous and more obvious in aged skulls and are formed by the arachnoid granulations, which are tuft-like protrusions of the arachnoid mater.

The anterior branch of the middle meningeal artery and its accompanying veins groove the bone deeply about 1 cm. behind the coronal suture, and their line corresponds more or less accurately to the precentral sulcus of the cerebrum. The rami of this artery and those of its posterior branch course upwards and backwards from the cut edge of the skull-cap, in grooves on the inner surface of the parietal bone. Smaller grooves produced by meningeal vessels may be present on the inner surfaces of the frontal and occipital bones (Pl. III). When present, the *parietal foramina* open on this surface near the sagittal groove about 3.5 cm. in front of the lambdoid suture. Each transmits an emissary vein from the superior sagittal sinus.

The *impressions for the cerebral gyri* are less distinct on the skull-cap than on the base of the skull and are seen best near the cut edge.

THE INTERNAL SURFACE OF THE BASE OF THE SKULL
(figs. 293, 312)

The internal surface of the base of the skull shows a natural subdivision into anterior, middle and posterior cranial fossæ. It is very irregular owing, partly, to

the impressions for the cerebral gyri, which are especially conspicuous in the anterior and middle fossæ, where they reflect accurately the pattern of the surface of the corresponding parts of the cerebrum. The dura mater is firmly adherent to the whole area, and through the numerous foramina and fissures the endocranium is continuous with the periosteum on the exterior of the skull.

THE ANTERIOR CRANIAL FOSSA (figs. 293, 312)

The **anterior cranial fossa** is limited in front and on each side by the frontal bone. Its floor is formed by the orbital parts of the frontal bone, the cribriform plate of the ethmoid and the lesser wings and anterior part of the body of the sphenoid.

The *cribriform plate of the ethmoid*, which stretches across the median plane, lies between the two orbital parts of the frontal bone, and is depressed below the level of the rest of the floor. It separates the fossa from the nasal cavity, the roof of which it helps to form (fig. 317). Anteriorly it presents a median crest-like elevation, termed the *crista galli*, which projects upwards between the two cerebral hemispheres. A depression intervenes between the front of the crista galli and the *crest of the frontal bone*, the floor of which is crossed by the fronto-ethmoidal suture and is marked by the presence of the *foramen cæcum*. On each side the crista galli is separated from the orbital part of the frontal bone by a narrow interval. The numerous small foramina which perforate the cribriform plate transmit the minute olfactory nerves from the nasal mucosa to the olfactory bulb. Posteriorly the cribriform plate articulates with the anterior part of the body of the sphenoid at the spheno-ethmoidal suture.

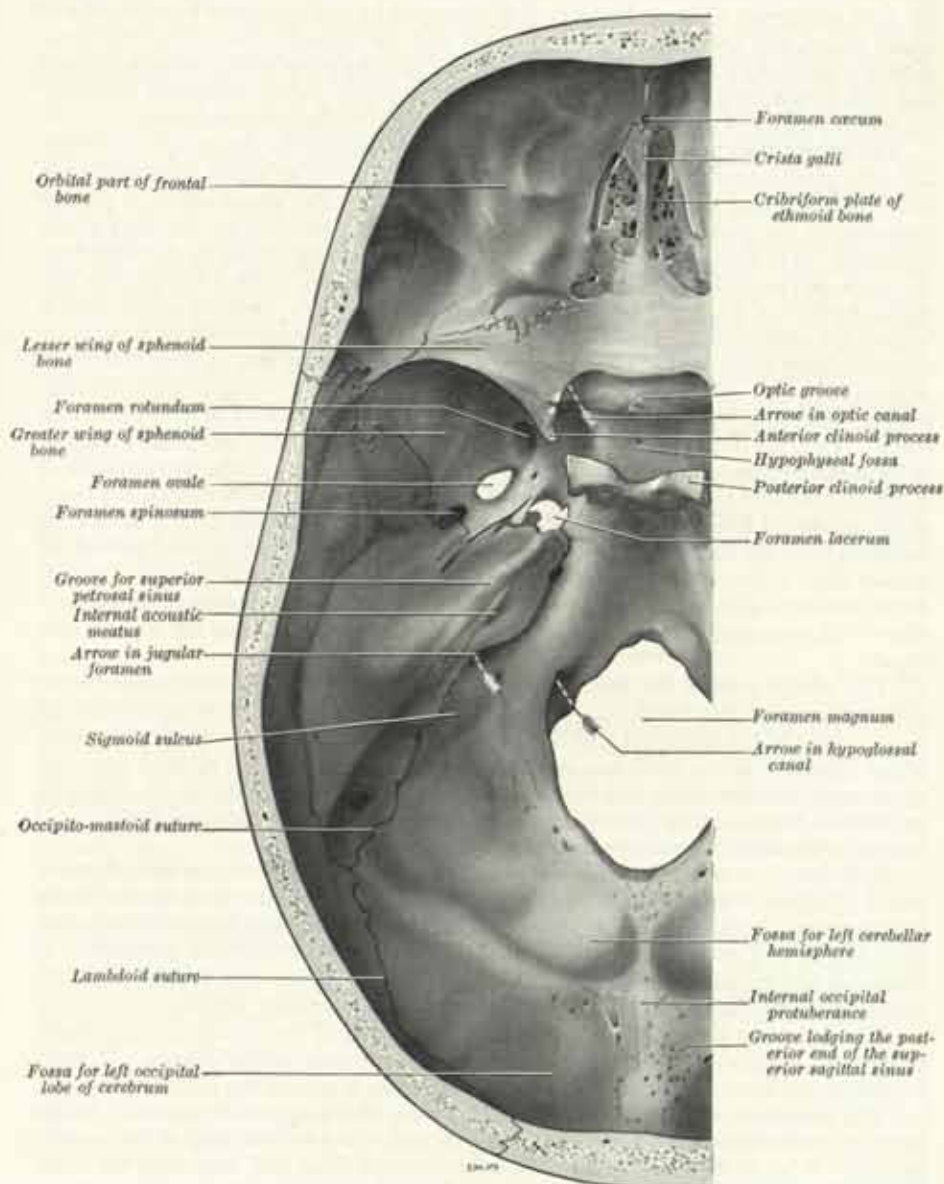
The *orbital part of the frontal bone* forms the greater part of the floor of the fossa on each side of the median plane and separates the orbit and its contents from the inferior surface of the frontal lobe of the brain. Its surface is convex upwards and is marked by impressions for the cerebral gyri and by one or two small grooves for meningeal vessels. In its anteromedial part it is split into two laminae to contain part of an air-space, termed the *frontal sinus*. The medial part of the orbital plate covers the ethmoidal labyrinth and shuts it out from the floor of the anterior cranial fossa. Posteriorly it articulates with the anterior border of the *lesser wing of the sphenoid bone*. In the median plane the cerebral surface of the frontal bone is marked by the *frontal crest*, which projects backwards into the interval between the two cerebral hemispheres and extends upwards on to the interior of the skull-cap.

Behind the cribriform plate the floor of the anterior cranial fossa is formed by the anterior portion of the upper surface of the body of the sphenoid. This part of the bone is termed the *jugum sphenoidale*, and it separates the fossa from an air-space contained in the body of the sphenoid and named the *sphenoidal sinus* (fig. 315). Anteriorly the jugum articulates with the posterior margin of the cribriform plate; posteriorly it is limited by the anterior border of a groove, usually termed the *optic groove*, which crosses the body of the sphenoid in the forepart of the middle cranial fossa and leads from one optic canal to the other. Lateral to the jugum the floor of the fossa is formed by the *lesser wing of the sphenoid*. The posterior margin of the lesser wing, which curves medially and backwards, is free and overhangs the most anterior part of the middle cranial fossa. Laterally the lesser wing tapers to a point and meets the suture between the frontal bone and the greater wing at or near the lateral end of the superior orbital fissure. The medial extremity of its posterior border forms a projection termed the *anterior clinoid process*. Medially the lesser wing is connected to the body of the sphenoid by two roots, separated from each other by the *optic canal*. The anterior root, broad and flat, is continuous with the jugum sphenoidale; the posterior root, smaller and thicker, is connected to the body of the sphenoid opposite the posterior border of the optic groove.

Particular features.—The *crista galli* and the *frontal crest* give attachment to the falx cerebri. The *foramen cæcum* between them usually ends blindly, but on rare occasions it is patent and transmits a vein from the nasal mucosa to the superior sagittal sinus. The narrow groove on the lateral side of the crista galli is related to the gyrus rectus and the olfactory bulb lies on the medial edge of the orbital part of the frontal bone. The *anterior ethmoidal canal* opens on the line of the suture between the orbital part of the frontal bone and the cribriform plate (fig. 346). It is placed behind the crista galli and is difficult to identify, for it is directed medially and is overlapped above by the medial edge of the orbital plate. It transmits the

anterior ethmoidal nerve and vessels, which run forward under the dura mater and gain the nasal cavity by passing downwards through a slit-like foramen at the side of the crista galli. The *posterior ethmoidal canal* opens at the posterolateral corner of the cribriform plate and is overhung by the anterior border of the sphenoid. It transmits the posterior ethmoidal vessels, but the posterior ethmoidal nerve terminates by supplying the mucous lining of the sphenoidal and posterior ethmoidal sinuses.

FIG. 312.—The upper surface of the left half of the base of the skull.



The free, posterior border of the *lesser wing* of the sphenoid fits into the stem of the lateral cerebral sulcus and may be grooved by the sphenoparietal sinus. Above, the lesser wing is related to the posterior part of the inferior surface of the frontal lobe and medially to the anterior perforated substance. Inferiorly it forms the upper boundary of the superior orbital fissure and helps to complete the roof of the orbit. The *anterior clinoid process* gives attachment to the free border of the tentorium cerebelli and is grooved on its medial aspect by the internal carotid artery as it pierces the roof of the cavernous sinus. Not infrequently the anterior clinoid process is connected to the middle clinoid process by a thin bar of bone, which completes a foramen around

the internal carotid artery. The flat surface of the *jugum sphenoidale* supports the posterior ends of the gyri recti and the olfactory tracts.

THE MIDDLE CRANIAL FOSSA (figs. 293, 312)

The **middle cranial fossa** is deeper than the anterior; it is more extensive on each side than in the median plane, and its walls bear some resemblance to a butterfly with outspread wings. In front it is bounded by the posterior borders of the lesser wings, the anterior clinoid processes and the anterior margin of the optic groove; behind by the superior borders of the petrous parts of the temporal bones and the dorsum sellæ of the sphenoid bone; laterally by the temporal squamæ, the frontal angles of the parietal bones and the greater wings of the sphenoid.

In the **median area** the floor is formed by the body of the sphenoid. In front, the *optic groove* leads on each side into the optic canal. The sulcus does not lodge the optic chiasma, which lies above and behind it. The **optic canal** is placed between the two roots of the lesser wing and is bounded medially by the body of the sphenoid. It is directed forwards, laterally and somewhat downwards and transmits the optic nerve and the ophthalmic artery. Immediately behind the groove the upper surface of the body of the sphenoid is shaped like a Turkish saddle and is termed the *sella turcica*. Its anterior slope is marked by a median elevation, termed the *tuberculum sellæ*, and behind that the surface is hollowed out to form the *hypophyseal fossa* (fig. 312), which lodges the hypophysis cerebri—an important ductless gland. The floor of the hypophyseal fossa forms part of the roof of the sphenoidal sinus. (Pl. III.) Posterior to the fossa a plate of bone projects upwards and forwards to form the *dorsum sellæ*. On each side the superolateral angle of the dorsum sellæ is expanded to form the *posterior clinoid process*. Lateral to the *sella turcica* the body of the sphenoid presents a shallow *groove for the internal carotid artery*, as it runs forwards from the foramen lacerum. A small elevation marks the anterior part of the medial edge of the carotid groove and is termed the *middle clinoid process*; it may be joined to the anterior clinoid process by a thin bar of bone. Posteriorly the lateral edge of the carotid groove may be deepened by a small projection termed the *lingula*.

The **lateral part of the middle cranial fossa** is deep and its floor supports the temporal lobe of the brain. It is formed in front by the cerebral surface of the greater wing of the sphenoid and behind by the anterior surface of the petrous part of the temporal bone, while the cerebral surface of the temporal squama occupies the interval between these two bones in the lateral portion of the floor. It is related in front to the posterior part of the orbit; laterally, to the temporal fossa; and below, to the infratemporal fossa.

Anteriorly it communicates with the orbit through the **superior orbital fissure**, which is bounded above by the lesser wing, below by the greater wing, and medially by the side of the body of the sphenoid. The fissure is wider at its medial end than at its lateral end and its long axis is directed upwards, laterally and forwards. It transmits the terminal branches of the ophthalmic nerve, the ophthalmic veins, the oculomotor, trochlear and abducent nerves, and some smaller vessels.

The **foramen rotundum** pierces the greater wing of the sphenoid immediately below and a little behind the medial end of the superior orbital fissure. It leads forwards into the pterygopalatine fossa, to which it conducts the maxillary nerve.

The **foramen ovale** pierces the greater wing of the sphenoid posterior to the foramen rotundum and lateral to the lingula and the posterior end of the carotid groove. It leads downwards into the infratemporal fossa and transmits the mandibular nerve to that region.

The **foramen spinosum** lies close to the posterolateral margin of the foramen ovale, and transmits the middle meningeal artery. The artery, with its accompanying veins, runs laterally to gain the temporal squama on which it runs upwards, forwards and laterally. Crossing the sphenosquamosal suture for a second time it ascends on the greater wing and divides into anterior and posterior branches. The anterior branch proceeds upwards *across the cerebral surface of the pterion* (p. 277) and gains the anterior part of the parietal bone. In the region of the pterion the artery is often enclosed in a bony canal. The posterior branch runs backwards and upwards on to the upper part of the temporal squama and crosses the squamosal

suture to gain the posterior part of the parietal bone. These arteries and their accompanying veins produce conspicuous grooves in the floor and lateral wall of the middle cranial fossa.

At the posterior end of the carotid groove and posteromedial to the foramen ovale the **foramen lacerum** is situated. It is bounded behind by the apex of the petrous temporal and in front by the body of the sphenoid and the posterior border of its greater wing. This end of the foramen lacerum transmits the internal carotid artery and its accompanying nervous and venous plexuses, together with some smaller structures.

Behind the foramen lacerum the anterior surface of the petrous temporal presents a shallow depression adjoining the apex of the bone. It is occupied by the trigeminal ganglion, and is named the *trigeminal impression*. The ganglion lies in a special recess of the dura mater and extends forwards above the lateral part of the foramen lacerum. Posterolateral to the trigeminal impression the surface presents a shallow hollow, limited posteriorly by a transversely rounded elevation, termed the *arcuate eminence*. This elevation is produced by the superior semicircular canal, which is closely related to the floor of the middle cranial fossa in this situation.

Lateral to the trigeminal impression the anterior surface of the petrous temporal presents a narrow groove which is directed backwards and laterally and soon disappears into the *hiatus for the greater petrosal nerve*. Anterolateral to the arcuate eminence the anterior surface of the petrous temporal is formed by the **tegmen tympani**, a thin lamella of bone which forms the roof of the tympanic cavity, and extends forwards and medially above the auditory tube. Lateral to the arcuate eminence the posterior part of the tegmen tympani forms the roof of the mastoid antrum—an air-space in the bone which communicates in front with the tympanic cavity.

The *superior border of the petrous temporal* separates the middle cranial fossa from the posterior cranial fossa. Behind the trigeminal impression it is grooved by the superior petrosal sinus, which connects the posterior end of the cavernous sinus to the upper end of the sigmoid sinus.

Particular features.—The optic nerve carries with it through the **optic canal** a sheath derived from the membranes of the brain. The ophthalmic artery lies below the nerve, and in contact with the posterior root of the lesser wing.

On each side of the body of the sphenoid the cavernous sinus extends from the medial end of the superior orbital fissure to the apex of the petrous part of the temporal bone. In addition to the internal carotid artery and its plexus of sympathetic nerves the sinus contains the oculomotor, the trochlear, abducent and ophthalmic nerves, but these structures do not come into contact with the bone. An anterior intercavernous sinus, which crosses the *tuberculum sellæ*, and a posterior intercavernous sinus, which crosses the front of the *dorsum sellæ*, connect the two cavernous sinuses to each other. The diaphragma sellæ, which surrounds the infundibulum, is connected to the tuberculum in front and to the dorsum sellæ behind. The *posterior clinoid process* gives attachment to the anterior extremity of the attached margin of the tentorium cerebelli and to the petrosphenoid ligament (p. 1114).

The **superior orbital fissure** (fig. 299) opens into the orbit between its roof and its lateral wall. Its lower border is marked by a small projection which gives attachment to the lateral part of the anulus tendineus communis. At the lateral extremity of the fissure the greater wing articulates with the orbital part of the frontal bone. (See also p. 275.)

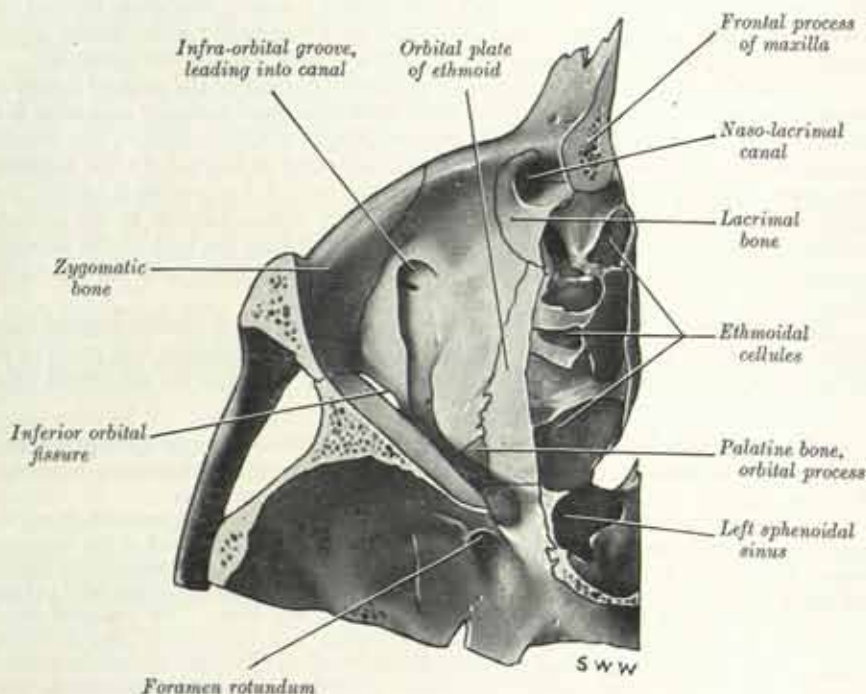
The **foramen rotundum**, like the medial end of the superior orbital fissure, is intimately related to the lateral wall of the sphenoidal sinus. Originally a part of the fissure, it becomes separated secondarily. A small foramen may be present at the root of the greater wing medial to the foramen ovale; it transmits an emissary vein from the cavernous sinus and is often termed the *emissary sphenoidal foramen*. In addition to the mandibular nerve the **foramen ovale** transmits the accessory meningeal artery, and, sometimes, the lesser petrosal nerve. In addition to the middle meningeal artery the **foramen spinosum** transmits the meningeal branch of the mandibular nerve. Both these foramina are represented at first by notches on the margin of the greater wing, which subsequently become converted into foramina.

The **foramen lacerum**, as described above (p. 286), is a short bony canal, traversed in its whole extent only by minute meningeal branches from the ascending pharyngeal artery and a few small veins. The internal carotid artery pierces its posterior wall and ascends through its upper opening. The greater petrosal nerve emerges from its hiatus and runs forwards in the groove which marks the anterior surface of the petrous part of the temporal bone. It turns downwards through the

foramen lacerum on the lateral side of the internal carotid artery and is joined by the deep petrosal nerve to form the nerve of the pterygoid canal. This nerve leaves the foramen lacerum above its lower opening by traversing the *pterygoid canal*, which opens on its anterior wall. The lesser petrosal nerve lies to the lateral side of the greater as it emerges on the anterior surface of the petrous part of the temporal bone and may occupy a small groove.

In a young skull the suture between the petrous and the squamous parts of the temporal bone may be visible at the lateral limit of the **tegmen tympani**, but it is usually obliterated in the adult skull. In this situation anteriorly, the lateral margin of the tegmen tympani turns downwards, forming the lateral wall of the bony part of the auditory tube, and its lower border may be visible in the floor of the squamo-tympanic fissure (p. 288).

FIG. 313.—A horizontal section through the nasal and orbital cavities of the left side. Superior aspect.



Lateral to the anterior part of the tegmen tympani the part of the temporal squama which helps to form the floor of the middle cranial fossa is thin and translucent over a small area. This corresponds to the deepest part of the mandibular fossa on the external surface of the base of the skull.

In front of the commencement of the groove for the superior petrosal sinus the upper border of the *petrous temporal* shows a shallow, smooth notch, often termed the *trigeminal notch*, which leads into the *trigeminal impression*. In this situation the roots of the trigeminal nerve intervene between the superior petrosal sinus and the bone. A tiny spicule, directed forwards and medially, marks the anterior extremity of the notch and gives attachment to the lower end of the petrosphenoidal ligament. The abducent nerve bends forwards sharply across the upper border of the petrous part of the temporal bone immediately in front of this bony spicule,* and so lies between the petrosphenoidal ligament and the side of the *dorsum sellæ*.

THE POSTERIOR CRANIAL FOSSA (figs. 293, 312)

The posterior fossa is the largest and deepest of the three cranial fossæ. It is bounded in front by the *dorsum sellæ*, the posterior part of the body of the sphenoid and the basilar part of the occipital bone; behind, by the lower portion of the squa-

* E. Wolff, *J. Anat.*, 63, 1929.

mous part of the occipital bone; on each side, by the petrous and mastoid parts of the temporal bone, the lateral (condylar) part of the occipital bone and, above and behind, by a small part of the mastoid angle of the parietal bone. It contains the cerebellum behind and the pons and medulla oblongata in front.

The **foramen magnum** (p. 289) is in the floor of the fossa and is surrounded by the parts of the occipital bone. Its circumference is formed by the basilar part in front, by the lateral part on each side and by a small portion of the squamous part behind. Just in front of its transverse diameter it is encroached on by the irregular, medial aspects of the occipital condyles, so that it is somewhat ovoid in shape and is wider behind than in front. Its narrower, anterior part lies above the dens of the axis vertebra; its wider posterior part communicates below with the vertebral canal, and through it the medulla oblongata passes down to become continuous with the spinal medulla.

In front of the foramen magnum the basilar part of the occipital bone, the posterior part of the body of the sphenoid bone and the dorsum sellæ form a sloping surface, gently concave from side to side, to support the medulla oblongata below and the pons above. On each side this area is separated from the petrous part of the temporal bone by the petro-occipital fissure, which is occupied in the recent state by a thin plate of cartilage. The fissure is limited behind by the jugular foramen, and its margins are grooved by the inferior petrosal sinus.

The **jugular foramen** (p. 290) lies at the posterior end of the petro-occipital fissure, and leads forwards, downwards and laterally to the external surface of the base. Its upper border is sharp and irregular and presents a *notch for the glossopharyngeal nerve*. Its lower border is smooth and regular. The posterior part of the foramen transmits the sigmoid sinus, which is continuous below with the internal jugular vein. In front of the vein the accessory, vagus and glossopharyngeal nerves, in that order from behind forwards, traverse the foramen to gain the upper part of the neck. The most anterior part of the foramen transmits the inferior petrosal sinus.

Medial to the lower border of the jugular foramen a rounded elevation, termed the *jugular tubercle*, marks the condylar part of the occipital bone. It lies above and somewhat in front of the inner opening of the **hypoglossal canal**, which pierces the bone at the junction of the basilar with the lateral part and transmits the hypoglossal nerve.

The posterior surface of the petrous part of the temporal bone forms a large portion of the lateral (or anterolateral) wall of the posterior fossa. Above the anterior part of the jugular foramen the **internal acoustic meatus** (fig. 312) runs transversely in a lateral direction. It is a short passage, about 1 cm. long, closed laterally by a perforated plate of bone which separates it from the internal ear. It transmits the facial and stato-acoustic (auditory) nerves.

Behind the petrous temporal the lateral wall of the posterior cranial fossa is formed by the mastoid part of the temporal bone. Anteriorly it is marked by a wide groove, which runs forwards and downwards, then downwards and medially, and finally forwards to the posterior limit of the jugular foramen. This groove contains the sigmoid sinus and is termed the **sigmoid sulcus** (fig. 312). At its upper end, where it touches the mastoid angle of the parietal bone, the groove is continuous with that for the transverse sinus and crosses the parietomastoid suture. As it descends, it lies *behind the mastoid (tympanic) antrum* and forms a very important relation of that cavity. In this part of its course the *mastoid foramen* opens near its posterior margin and transmits an emissary vein from the sinus. In its lowest part the sigmoid sulcus crosses the occipitomastoid suture and grooves the jugular process of the occipital bone. It is usually deeper on the right than on the left side.

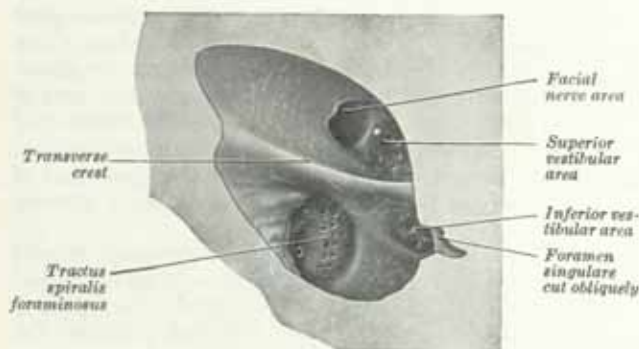
Behind the foramen magnum the squamous part of the occipital bone is marked in or near the median plane by the *internal occipital crest*, which ends above and behind in an irregular elevation named the *internal occipital protuberance*. On each side of the protuberance a wide shallow groove curves laterally with a slight upward convexity to the mastoid angle of the parietal bone. It is produced by the transverse sinus, is usually deeper on the right side, and at its lateral extremity is continuous with the groove for the sigmoid sinus. Below the groove for the transverse sinus the internal occipital crest divides the bone into two gently hollowed fossæ, which lodge the cerebellar hemispheres.

When the *condylar canal* is present (fig. 327), its inner orifice lies behind and lateral to the orifice of the hypoglossal canal. It transmits an emissary vein from the lower end of the sigmoid sinus.

Particular features.—The anterior wall of the fossa is related to the plexus of basilar sinuses which connects the two inferior petrosal sinuses and communicates below with the internal vertebral venous plexus. A little in front of the foramen magnum the *membrana tectoria* is attached to the basilar part of the occipital bone (fig. 494), covering the attachment of the apical ligament of the dens. The *jugular tubercle* is often grooved by the glossopharyngeal, vagus and accessory nerves, as they pass to the jugular foramen. In addition to the hypoglossal nerve the **hypoglossal canal** transmits a meningeal branch of the ascending pharyngeal artery. The canal is often subdivided into two parts by a small bar of bone, and this may be related to the composite origin of the hypoglossal nerve (p. 1137). The roughened medial aspect of the *occipital condyle* (fig. 327) gives attachment to the alar ligament.

The lower and posterior borders of the **jugular foramen** (pp. 290, and 297) are smooth and regular, but its upper border is sharp and interrupted by a notch, the ends of which may succeed in dividing the foramen into two or sometimes three compartments. At its deepest part the notch is

FIG. 314.—The fundus of the right internal auditory meatus, exposed by a section through the petrous part of the right temporal bone nearly parallel to its long axis.



pierced by the *cochlear canaliculus*, which contains the perilymphatic duct (aqueduct of the cochlea).

The **internal acoustic meatus** transmits the stato-acoustic (auditory) nerve, both the motor and the sensory roots of the facial nerve and the labyrinthine vessels. It is about 1 cm. in length and its *fundus* is separated from the internal ear by a vertical plate which is divided into two

unequal portions by a *transverse crest* (fig. 314). Above the crest anteriorly the bone is pierced by the **facial canal**, which conducts the facial nerve through the petrous temporal to the stylo-mastoid foramen. Behind the opening of the facial canal there is a small depression, termed the *superior vestibular area*, which presents a number of openings for the passage of the nerves to the utricle and the superior and lateral semicircular ducts. Below the transverse crest anteriorly lies the *cochlear area*, in which a number of small, spirally arranged openings encircle the central canal of the cochlea and constitute the *tractus spiralis foraminosus*. Behind the cochlear area the *inferior vestibular area* presents several openings for the nerves to the saccule. Below and behind the inferior vestibular area the *foramen singulare* gives passage to the nerve to the posterior semicircular duct.

Behind the orifice of the internal acoustic meatus a thin plate of bone with an irregularly curved margin projects backwards, and the slit which it bounds contains the external opening of the *aqueduct of the vestibule* (fig. 335). Within the aqueduct the saccus and ductus endolymphaticus (p. 1286) are contained together with a small artery and vein. In the area between the internal acoustic meatus and the external opening of the aqueduct of the vestibule there is a small depressed area, termed the *subarcuate fossa*, which lodges a small process of the dura mater. It lies nearer to the upper border of the bone (fig. 335) and is pierced by a small vein. In the infant the fossa is relatively large and extends as a short blind tunnel under the superior semicircular canal; it corresponds to the floccular fossa in some animals.

In addition to an emissary vein, the *mastoid foramen* transmits a meningeal branch of the occipital artery, which is sometimes large enough to produce a groove on the squamous part of the occipital bone.

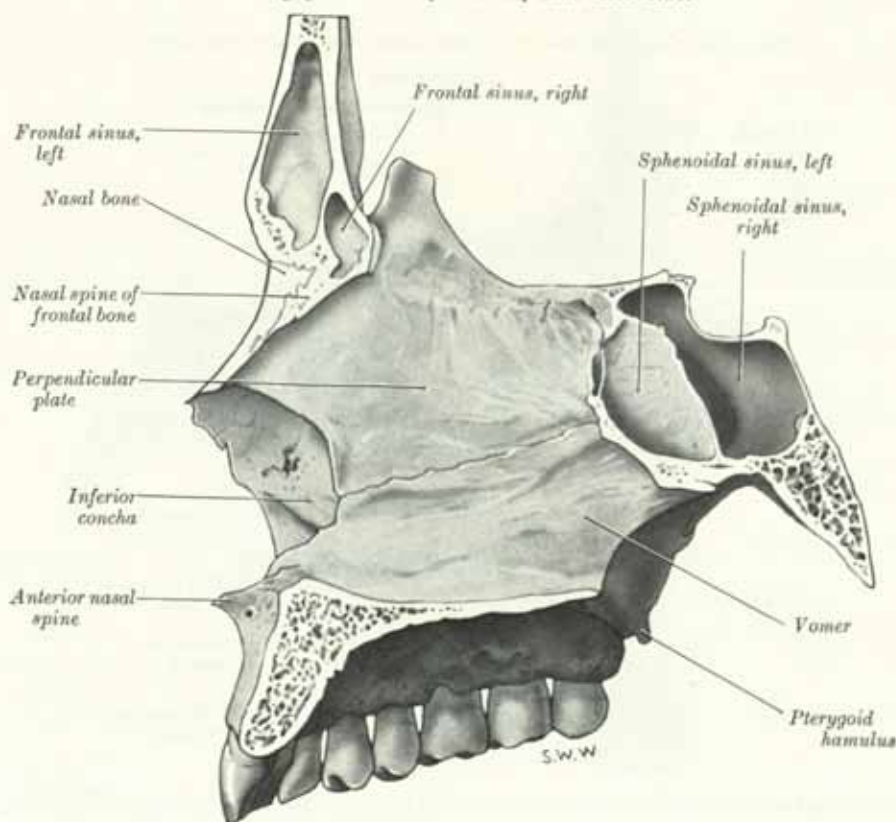
The *internal occipital crest* gives attachment to the *falx cerebelli* and may be grooved by the occipital sinus, which is sometimes duplicated and is occasionally a large vessel. Its lower end is related to the inferior vermis of the cerebellum. The *internal occipital protuberance* is related to the confluence of sinuses and is grooved on each side by the commencement of the transverse sinus. The margins of the *groove for the transverse sinus* give attachment to the two layers of the *tentorium cerebelli*. Traced in a lateral direction, the groove reaches the lowest part of the mastoid angle of the parietal bone,

where it becomes continuous with the groove for the sigmoid sinus. On each side of the internal occipital crest the bone is thin and translucent, in marked contrast to the regions of the crest and of the internal occipital protuberance.

THE NASAL CAVITY

The **nasal cavity** is the first of the respiratory passages and is an irregularly shaped space which extends from the roof of the mouth upwards to the base of the skull. It is subdivided into right and left halves by a *septum* (fig. 315), which is approximately median in position. In the dried skull the septum is deficient anteriorly, and as a result a single *anterior nasal aperture* is present on the norma

FIG. 315.—The bony nasal septum. Left side.



frontalis. The septum, however, reaches the posterior limit of the cavity, which communicates with the nasal part of the pharynx through a pair of *posterior nasal apertures*, placed immediately above the posterior border of the bony plate. The cavity is wider below than above and is widest and deepest in its central part. It communicates with the frontal, ethmoidal, maxillary and sphenoidal sinuses.

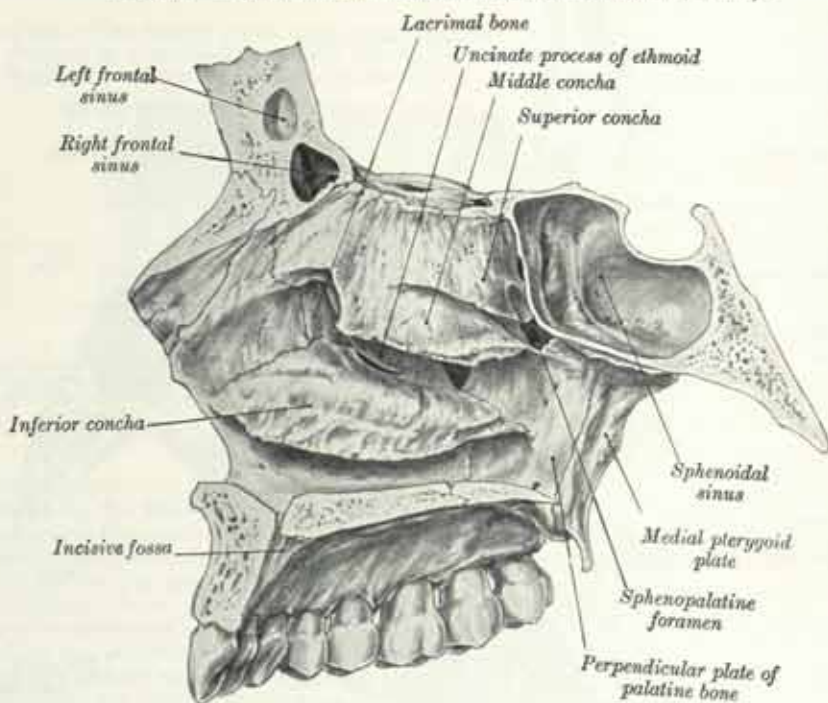
Each half of the nasal cavity has a roof, a floor, a lateral and a medial wall—the medial wall being formed by the corresponding side of the nasal septum.

The **roof** (figs. 315, 316) is horizontal in its middle part but slopes downwards in front and behind. The anterior sloping part is formed by the frontal and nasal bones and contributes to the formation of the external nose. The horizontal part is formed by the cribriform plate of the ethmoid bone and separates the nasal cavity from the medial part of the floor of the anterior cranial fossa. It presents numerous small openings for the passage of the olfactory nerves. The posterior sloping part is formed by the body of the sphenoid and is interrupted, on each side, by the rounded orifice of the sphenoidal sinus.

The **floor** is smooth, gently concave from side to side, and slopes upwards a little as it passes backwards from the anterior aperture to the posterior aperture. It is formed by the upper surface of the bony palate and therefore intervenes between the nasal and oral cavities. Anteriorly the palatine processes of the two maxillæ meet in the median plane, and behind them the horizontal plates of the palatine bones articulate with each other in the median plane and with the palatine processes of the maxillæ in front. In its anterior part the floor close to the septum presents a small funnel-shaped opening which leads into the *incisive canals* (p. 345).

The **medial wall** is formed by the *bony septum* (fig. 315), which extends between the roof and the floor. It is a thin sheet of bone and presents a wide deficiency in front, occupied in the recent state by the septal cartilage. It is formed almost entirely by the vomer and the perpendicular plate of the ethmoid. The *vomer* extends from the under surface of the body of the sphenoid to the bony palate and forms the lower and posterior part of the septum, including its free, posterior border.

FIG. 316.—The roof, floor and right lateral wall of the nasal cavity.



It is marked by small furrows for vessels and nerves. The *perpendicular plate of the ethmoid* forms the upper and anterior part of the septum (fig. 315) and is continuous above with the cribriform plate (p. 292). The septum is often deflected to one or other side, and the deviation occurs most commonly in the line of the vomero-ethmoidal suture.

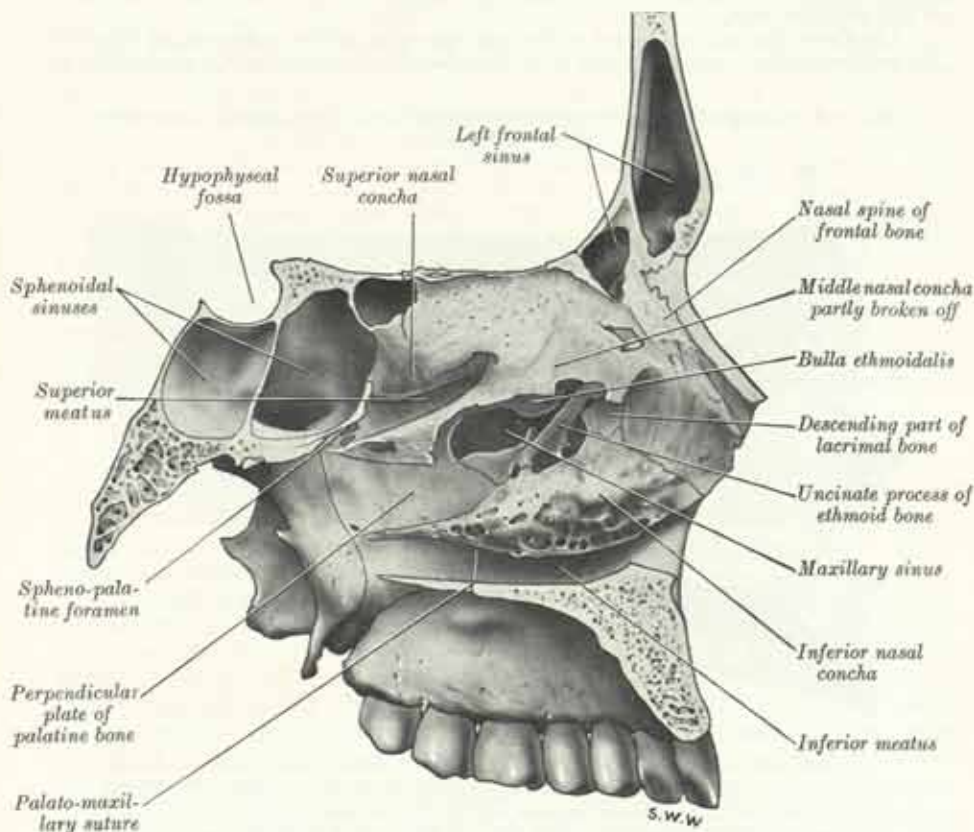
The **lateral wall** (figs. 316, 317) is very irregular owing to the presence of three bony projections termed the inferior, middle and superior nasal conchæ. It is formed, for the most part, by the nasal surface of the maxilla below and in front, by the perpendicular plate of the palatine bone posteriorly, and above by the nasal surface of the ethmoidal labyrinth, which intervenes between the nasal cavity and the orbit. The three conchæ project downwards and slightly medially, and each forms the roof of a passage which communicates freely with the nasal cavity. These passages are termed the *meatuses of the nose*.

The *inferior concha* is a curved lamina of thin bone and is an independent entity. It articulates with the nasal surface of the maxilla and the perpendicular plate of the palatine bone, and possesses a free lower border, which is gently curved. The *inferior meatus* lies under cover of the inferior concha and extends downwards to the floor of the nasal cavity. It is the largest of the three meatuses and extends almost

the entire length of the lateral wall of the nose. The inferior meatus is deepest at the junction of its anterior and middle thirds, and in this situation it presents the lower orifice of the nasolacrimal canal.

The *middle* and *superior conchæ* are projections from the medial surface of the ethmoidal labyrinth. The *middle concha* is much the larger and extends backwards to articulate with the perpendicular plate of the palatine bone. The *middle meatus* is placed between the middle and inferior conchæ. Its lateral wall displays several important features which can be examined only after the removal of the middle concha (fig. 317). Its upper part is occupied by a rounded elevation, termed the *ethmoidal bulla*, which contains the middle ethmoidal cellules. Below and in front

FIG. 317.—The lateral wall of the left nasal cavity, with an irregularly shaped portion removed from the lower part of the middle concha.



of the bulla a thin, curved lamina of bone, named the *uncinate process of the ethmoid*, passes downwards and backwards, crossing the large bony orifice of the maxillary sinus. The curved gap (fig. 317) which intervenes between this process and the ethmoidal bulla is termed the *ethmoidal hiatus* in the bony skull. At its upper end it becomes continuous with the *ethmoidal infundibulum*, a short, curved canal which receives the openings of the anterior ethmoidal cellules and then leads upwards through the labyrinth into the frontal sinus. In 50 per cent of skulls, however, the infundibulum ends blindly and the frontal sinus then opens directly into the upper and anterior part of the middle meatus. The middle ethmoidal cellules open above, or near, the bulla.

The *superior concha* is a small curved lamina which lies above and behind the middle concha. It roofs in the *superior meatus*, which is much the shortest and shallowest of the three meatuses; it receives the opening of the posterior ethmoidal cellules. Immediately behind the superior meatus the spheno-palatine foramen, which opens into the pterygopalatine fossa, pierces the lateral wall of the nasal cavity. A narrow interval, termed the *spheno-ethmoidal recess*, separates the superior

concha from the anterior surface of the body of the sphenoid, through which the sphenoidal sinus opens into the nasal cavity.

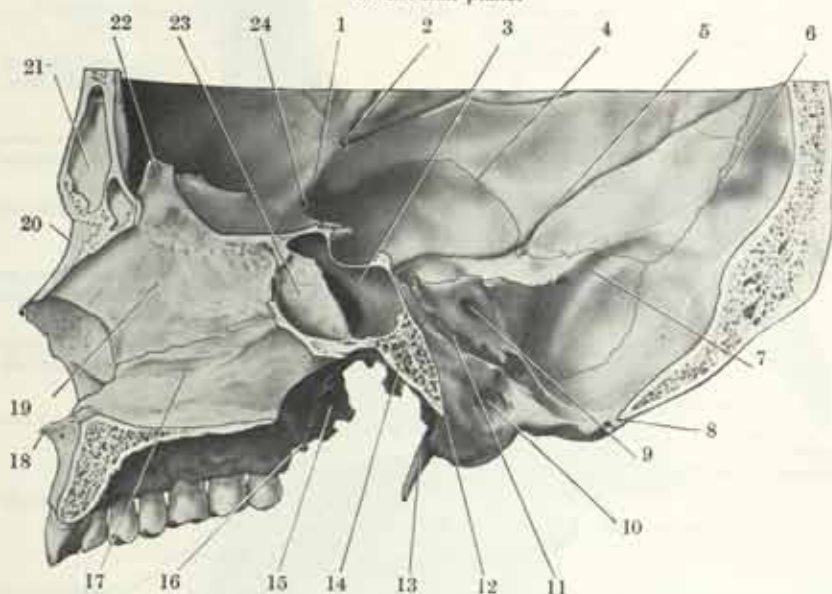
The **anterior nasal aperture** has been described on p. 271.

The **posterior nasal apertures**, or **choanæ** are separated from each other by the posterior border of the vomer. They are bounded below, on each side, by the posterior border of the horizontal plate of the palatine bone, above by the base of the skull; and laterally, on each side, by the medial pterygoid plate.

Particular features.—The anterior sloping part of the **roof** (fig. 316) is formed by the nasal bone and the nasal spine of the frontal bone. In addition to the numerous small foramina for the transmission of the olfactory nerves, the horizontal part of the roof presents a separate foramen, situated anteriorly, which gives passage to the anterior ethmoidal nerve and vessels. The posterior sloping part of the roof is formed above by the anterior aspect of the body of the sphenoid, with which the sphenoidal concha (p. 318) is fused, and below by the ala of the vomer and the sphenoidal process of the palatine bone.

The **floor** (fig. 316) is crossed at the junction of its middle and posterior thirds by the palatamaxillary suture. Close to the median plane anteriorly it is pierced by the

FIG. 318.—A sagittal section through the lower part of the skull, slightly to the left of the median plane.



1. Frontosphenoidal suture. 2. Bony canal for middle meningeal vessels, anterior divisions, upper orifice. 3. Right sphenoidal sinus. 4. Squamosal suture. 5. Groove for posterior branches of middle meningeal vessels. 6. Lambdoid suture. 7. Groove for transverse sinus. 8. Posterior margin of foramen magnum. 9. Internal acoustic meatus. 10. Hypoglossal canal. 11. Petro-occipital suture in floor of groove for inferior petrosal sinus. 12. Anterior margin of foramen magnum. 13. Styloid process. 14. Line of occipitospinous junction. 15. Lateral pterygoid plate. 16. Pterygoid hamulus. 17. Vomer. 18. Anterior nasal spine. 19. Perpendicular plate of ethmoid. 20. Nasal bone. 21. Frontal sinus. 22. Crista galli. 23. Left sphenoidal sinus. 24. Bony canal for anterior divisions of middle meningeal vessels, lower orifice.

incisive canal (p. 345). Both incisive canals open into the incisive fossa on the bony palate and they traverse the line of union of the os incisivum (premaxilla) with the maxilla; they represent a primitive communication between the mouth and the nose.

At the upper and lower borders of the **medial wall** (fig. 315) other bones, in addition to the vomer and the perpendicular plate of the ethmoid, make minor contributions to the septum. Above and in front, the nasal bones and the nasal spine of the frontal bone, above and behind, the rostrum and crest of the sphenoid, and below, the nasal crests of the maxillæ and palatine bones all take small parts in its formation. The vomer is grooved by the nasopalatine nerves, as they run downwards and forwards to reach the incisive canal.

The **lateral wall** (figs. 316, 317) is formed anteriorly and above by the nasal bone and the frontal process of the maxilla. Behind the frontal process of the maxilla, and articulating with its posterior border, the lacrimal bone lies in the lateral wall of the middle meatus and articulates below with the lacrimal process of the inferior concha.

These two bones form the medial wall of the nasolacrimal canal (fig. 317), which conveys the nasolacrimal duct to the inferior meatus. Posteriorly the lacrimal bone articulates with the ethmoidal labyrinth and helps to close some of the ethmoidal cells. The *uncinate process of the ethmoid* springs from this part of the labyrinth and curves downwards and backwards in the lateral wall of the middle meatus. It is a very thin and fragile process, about 3 mm. wide, which curves across the maxillary hiatus and articulates near its extremity with the ethmoidal process of the inferior concha. The concave, posterior border of the process is free and forms the medial edge of the ethmoidal hiatus (hiatus semilunaris); the convex anterior border is free in its upper part only. Owing to its position relative to the maxillary hiatus the uncinat process helps to form the medial wall of the maxillary sinus. The *maxillary hiatus*, which forms such a conspicuous opening on the nasal surface of the maxilla (fig. 363), is reduced in size very considerably by the neighbouring bones. Its lower part is covered by the inferior concha and its maxillary process; above the inferior concha the uncinat process of the ethmoid, as already stated, encroaches on the gap. Posteriorly the anterior part of the perpendicular plate of the palatine bone closes it in still further, and above and in front small portions of the ethmoidal labyrinth and the lacrimal bone overlap its margins (fig. 364). As a result, the maxillary hiatus is reduced sometimes to a single orifice in the floor of the posterior part of the hiatus semilunaris, although as a rule additional openings exist behind the uncinat process, and between its lower border and the upper border of the inferior concha. The *bullae ethmoidalis* is very variable in its size and shape and may be fused with the upper part of the uncinat process. In that event the duct of the frontal sinus opens into the upper part of the middle meatus medial to the blind end of the infundibulum. A third concha (*concha suprema*) is often present on the medial surface of the ethmoidal labyrinth above and behind the posterior end of the superior concha; it is little more than a slight ridge, separated from the superior concha by a shallow depression. The *sphenopalatine foramen* (fig. 316) lies at the posterior limit of the superior meatus. It transmits the sphenopalatine artery and the nasopalatine and superior nasal nerves from the pterygopalatine fossa. The foramen is bounded above by the body of the sphenoid and the sphenoidal concha; below by the notched upper border of the perpendicular plate of the palatine bone, and in front and behind by its orbital and sphenoidal processes respectively.

THE MANDIBLE [MANDIBULA] (figs. 319, 320)

The **mandible**, which is the largest and strongest bone of the face, has a curved, horizontal *body*, which is convex forwards, and two broad *rami*, which project upwards from the posterior ends of the body.

The **body** of the mandible is curved like a horseshoe, and possesses an external and an internal surface, separated by upper and lower borders. The *external surface* is marked in the upper part of the median plane by a faint ridge, often indistinguishable, which indicates the line of fusion of the two halves of the fetal bone (symphysis menti). Inferiorly the ridge divides to enclose a triangular raised area, termed the *mental protuberance*, the base of which is depressed in the centre but raised on each side to form the *mental tubercle*. Below the interval between the two premolar teeth, or below the second premolar, the *mental foramen*, which gives exit to the mental nerve and vessels, opens on the surface. A faint ridge, termed the *oblique line*, runs upwards and backwards from the mental tubercle, to become salient behind, where it is continuous with the anterior border of the ramus.

The lower border of the body is termed the *base of the mandible*. It extends backwards and laterally from the symphysis menti, and becomes continuous with the lower border of the ramus behind the third molar tooth. Near the median plane it presents a small, roughened depression, named the *digastric fossa*. Behind the digastric fossa the base is thick and rounded and presents a slight downward convexity.

The upper border of the body is formed by the *alveolar part*, which is hollowed into sixteen *sockets* for the roots of the teeth. These sockets vary in size and depth, and are single or subdivided by septa according to the teeth which they contain.

The *internal surface* is divided into two areas by an oblique ridge, termed the **mylohyoid line**. Sharp and distinct in the region of the molar teeth, it becomes almost indiscernible in front. It commences behind the third molar tooth, not quite 1 cm. from the upper border of the bone, and runs forwards and downwards to reach the symphysis menti in the interval between the two digastric fossae. Below the mylohyoid line the surface is slightly hollowed out and forms the *submandibular fossa* for the lodgment of the submandibular salivary gland. The area

FIG. 319.—The left half of the mandible. Lateral aspect.

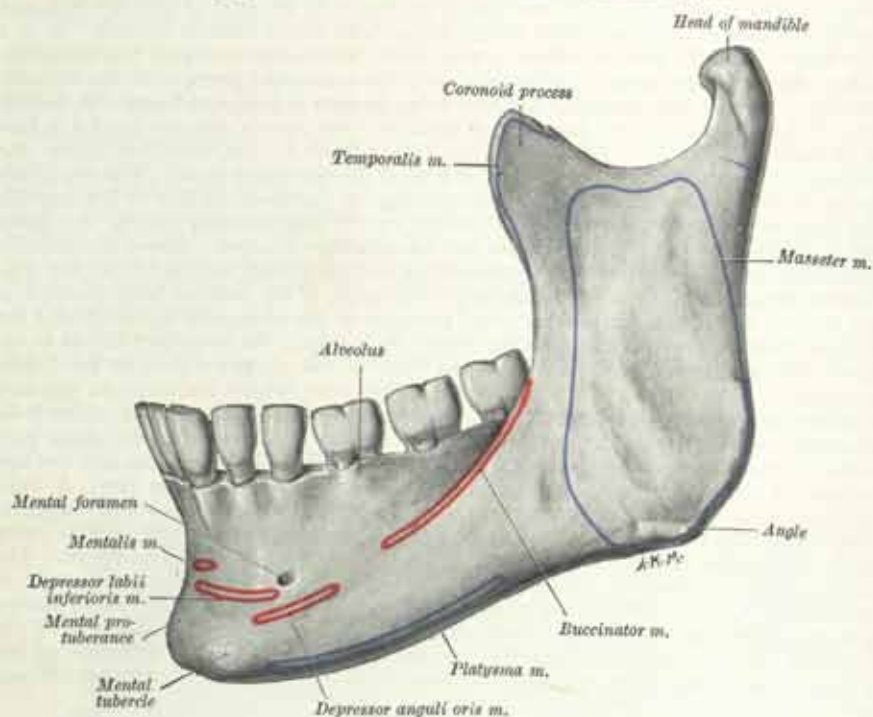
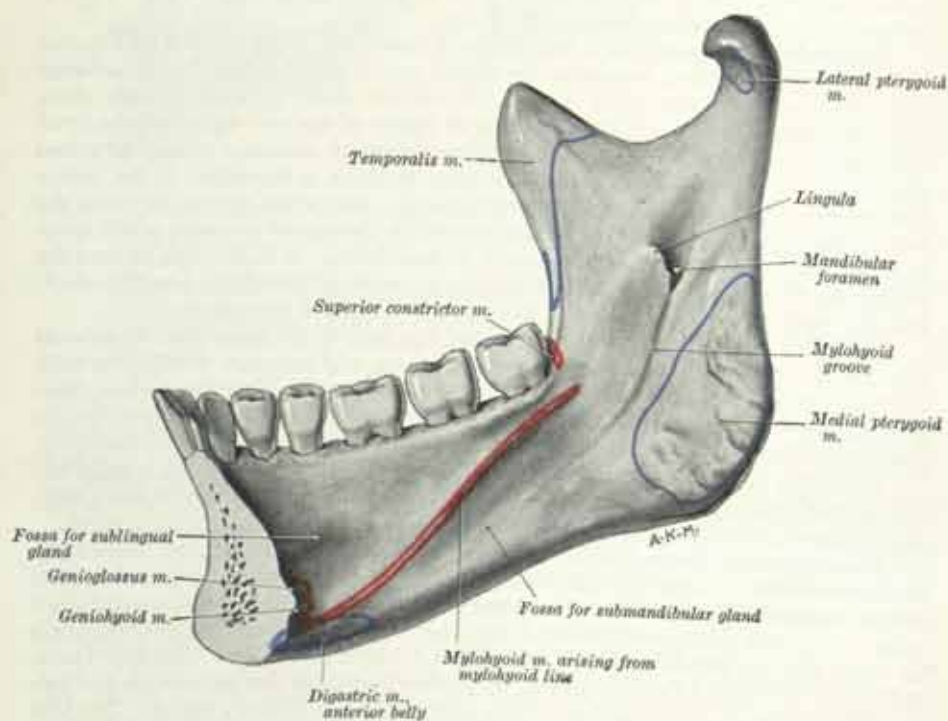


FIG. 320.—The right half of the mandible. Medial aspect.



above the mylohyoid line widens as it is traced forwards and presents in front a triangular area, termed the *sublingual fossa*, which lodges the sublingual gland. Above the sublingual fossa and extending backwards to the third molar tooth a strip of the bone is closely covered with the mucous membrane of the mouth. Above the anterior ends of the mylohyoid lines the posterior surface of the symphysis menti is marked by a small irregular elevation, which may be divisible into two or more parts, termed the *genial tubercles*. Posteriorly, a groove, termed the *mylohyoid groove*, extends downwards and forwards on to the body from the ramus and passes below the posterior end of the mylohyoid line.

The **ramus** (figs. 319, 320) of the mandible is quadrilateral in shape, and presents two surfaces, four borders and two prominent processes. The *lateral surface* is flat and marked by oblique ridges in its lower part. The *medial surface* presents, a little above its centre, an irregular opening, named the *mandibular foramen*. This opening leads into the *mandibular canal*, which curves downwards and forwards into the body of the bone to open on the external surface at the mental foramen (*vide infra*). In front and on the medial side the foramen is obscured by a thin triangular process termed the *lingula*. The *mylohyoid groove* commences behind the lingula and runs downwards and forwards to reach the internal surface of the body. The part of the medial surface which lies behind the groove is marked by a number of short rough ridges. The *inferior border* of the ramus is continuous in front with the base of the mandible; behind, it meets the posterior border at the **angle of the mandible**. Eversion of the angle is characteristic of the male mandible; in the female it is frequently inverted. The *upper border* is thin and bounds a wide notch, termed the *mandibular notch*. It is surmounted in front by a triangular, flattened projection, termed the coronoid process, and behind by a stout, articular process named the condylar process. The *posterior border*, thick and rounded, extends from the back of the condylar process to the angle of the mandible. It is gently curved, being convex backwards above and concave below, and is intimately related to the parotid salivary gland. The *anterior border* is thin above, where it is continuous with the anterior border of the coronoid process, and thicker below, where it is continuous with the oblique line.

The **coronoid process** is a flattened triangular projection, directed upwards and slightly forwards in the living subject. Its posterior border bounds the mandibular notch and its anterior border is continuous with the anterior border of the ramus. Its margins and medial surface provide insertion for most of the fibres of the temporalis muscle. The **condylar process** is expanded above to form the *head* of the mandible, which is covered with fibrocartilage. It articulates with the mandibular fossa of the temporal bone—an articular disc intervening. It is convex in all directions and its transverse measurement is greater than its anteroposterior. The lateral aspect of the head forms a blunt point which projects beyond the lateral surface of the rest of the ramus and *can be felt in the living subject just in front of the tragus of the auricle*. When the mouth is opened the head passes downwards and forwards, and the examining finger sinks into a small depression. The constricted portion below the head is termed the *neck of the mandible*. It is slightly flattened from before backwards, and its anterior aspect is limited on the lateral side by the backward continuation of the margin of the mandibular notch. Medial to this ridge the anterior surface of the neck presents a rough muscular impression, termed the *pterygoid fovea*.

The **mandibular canal** runs from the mandibular foramen obliquely downwards and forwards in the ramus, and then horizontally forwards in the body below the sockets of the teeth, with which it communicates by small openings. It contains the inferior alveolar (dental) nerve and vessels, from which branches enter the roots of the teeth. Between the roots of the first and second premolars, or below the root of the second premolar tooth, the mandibular canal divides into *mental* and *incisive canals*; the mental canal runs upwards, backwards and laterally to reach the mental foramen; the incisive canal is continued forwards below the incisor teeth.

Particular features.—A small shallow fossa marks the bone below the incisor teeth and gives origin to the mentalis and a part of the orbicularis oris muscle. The anterior end of the oblique line gives origin to the depressor labii inferioris and the depressor anguli oris muscles. The platysma is inserted into the bone below these muscles and extends backwards beyond them. The lower margin of the **mental foramen** is sharp and the mental nerve is directed upwards and backwards as it

emerges from the bone. Adjoining the alveolar border the bone is closely covered with the mucous membrane of the mouth. Immediately below this area, in the region of the molar teeth, the buccinator muscle has a linear origin, which extends medially behind the last molar tooth to the attachment of the pterygomandibular raphe.

The **mylohyoid** line gives origin to the mylohyoid muscle. Above its posterior end the bone gives origin to fibres of the superior constrictor muscle of the pharynx, and the pterygomandibular raphe is attached immediately behind the third molar tooth. The lingual nerve gains the tongue by passing above the posterior end of the mylohyoid line and in this situation is closely related to the inner surface of the mandible. A strip of bone along the alveolar border is covered by the mucous membrane of the mouth, and the sublingual gland lies in contact with the bone anteriorly between this area and the mylohyoid line. The upper *genial tubercles* give origin to the genioglossi and the lower to the geniohyoid muscles; both tubercles are placed above the anterior ends of the mylohyoid lines. The *submandibular fossa* lodges some of the submandibular lymph glands in addition to the salivary gland, and the facial artery may come into contact with this region as it descends to curl round the base of the mandible, where it sometimes produces a shallow groove. The *digastric fossa* gives attachment to the anterior belly of the digastric and lies below the anterior end of the mylohyoid line.

The **ramus** and its processes provide insertion for all the principal muscles of mastication. Its *lateral surface* gives insertion to the masseter muscle, except at its upper and posterior part, where it is covered by the parotid gland.

The *medial surface* gives insertion to the medial pterygoid muscle at the roughened area which lies behind and below the mylohyoid groove. The **mandibular foramen** admits the inferior alveolar nerve and vessels to the mandibular canal. Its medial border is formed by the *lingula*, to which the lower end of the sphenomandibular ligament is attached. Posterior to the lingula the mylohyoid nerve and vessels enter the *mylohyoid groove*, which may be converted into a bony canal in a part of its extent. The groove reaches the body of the mandible below the posterior end of the mylohyoid line, and the nerve and vessels then pass on to the superficial aspect of the mylohyoid muscle. In front of the mylohyoid groove and below the lingula the medial surface of the ramus is related to the medial pterygoid muscle, but the lingual nerve intervenes between the muscle and the bone, as it runs downwards and forwards to reach the tongue. The lowest fibres of insertion of the temporalis muscle descend beyond the coronoid process and are attached to the *anterior border* of the ramus and the adjoining part of the medial surface. The area above and behind the mandibular foramen is related to the maxillary artery and its inferior alveolar branch, and the part adjoining the mandibular notch is in relation with the lateral pterygoid muscle. The *mandibular notch* transmits the masseteric nerve and vessels from the infratemporal fossa.

The **coronoid process** is covered on its lateral aspect by the anterior fibres of the masseter muscle as they pass downwards and backwards to be inserted into the ramus. Its apex, margins and medial surface receive the insertion of the temporalis muscle (fig. 320). If the finger is pressed into the yielding part of the cheek below the zygomatic bone, the anterior border of the coronoid process can be identified in the living subject when the mouth is opened. Owing to the way in which it is expanded, the **condylar process** projects beyond the surfaces of the ramus, but more so on the medial than on the lateral side. The articular *head of the mandible* extends only for a short distance down the anterior surface of the process, but it covers the whole of its superior aspect and descends for 5 mm. or more on its posterior aspect. Its superior aspect slopes medially and slightly downwards and backwards. Its projecting lateral part is separated from the cartilaginous part of the external acoustic meatus by a portion of the parotid gland. The smooth lateral aspect of the *neck of the mandible* gives attachment to the lateral ligament of the temporomandibular joint (fig. 485) and is covered by the parotid gland. The rough impression on the front of the neck receives the insertion of the lateral pterygoid muscle. The medial surface of the neck is related to the auriculo-temporal nerve above and to the maxillary artery below.

The relation of the parotid gland to the mandible requires special mention. It occupies the interval below the external acoustic meatus, bounded in front by the posterior border of the ramus, behind by the mastoid process and medially by the styloid process; but it extends forwards beyond this area and covers the lateral aspect of the temporomandibular joint and the part of the lateral surface of the ramus behind the masseter muscle. In addition it curls round the posterior border and comes into contact with the medial aspect of the ramus just above the insertion of the medial pterygoid muscle.

Ossification.—The mandible is ossified in the fibrous membrane covering the outer surfaces of Meckel's cartilages. This pair of cartilages form the skeletal elements of the mandibular arches (p. 109). Their dorsal or cranial ends are con-

nected with the cartilaginous ear-capsules, and their ventral ends are joined to each other by mesenchymal tissue. They run forwards below the condylar processes in the 95 mm. embryo and then, bending downwards and forwards, lie in a groove near the lower border of the bone (fig. 322); in front of the canine teeth they incline upwards to the symphysis menti. From the proximal end of each cartilage the malleus and incus—two of the three ossicles of the middle ear—are developed; the next succeeding portion, as far as the lingula of the mandible, disappears, but its sheath persists to form the sphenomandibular ligament. The portion below the incisor teeth is ossified and incorporated with the mandible but the intervening portion, after persisting for a time, is ultimately absorbed.

Each half of the bone is ossified from one centre,* which appears near the mental foramen about the sixth week of fetal life, i.e. just after the appearance

FIG. 321.—The right half of the mandible of a human embryo. 95 mm. long. Lateral aspect. (From a reconstruction model by A. M. Low.)

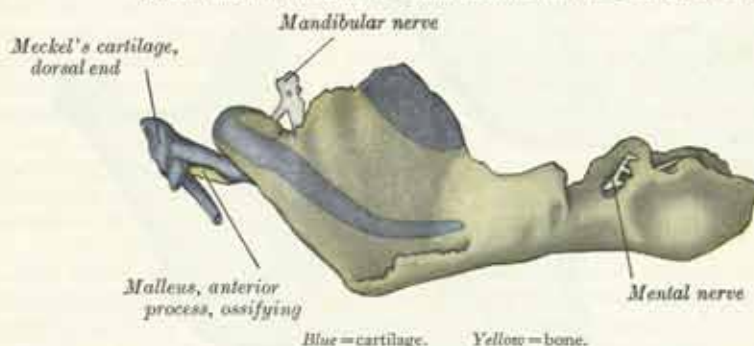
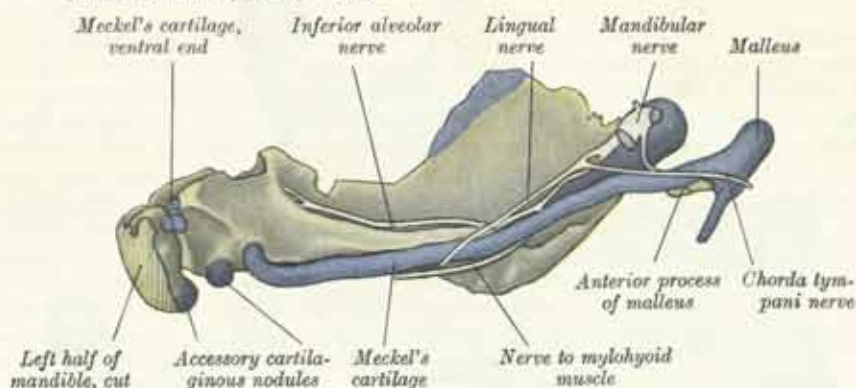


FIG. 322.—The right half of the mandible of a human embryo 95 mm. long. Medial aspect. The developing bone is shown in yellow, and the cartilage in blue. (From a model by A. M. Low.)



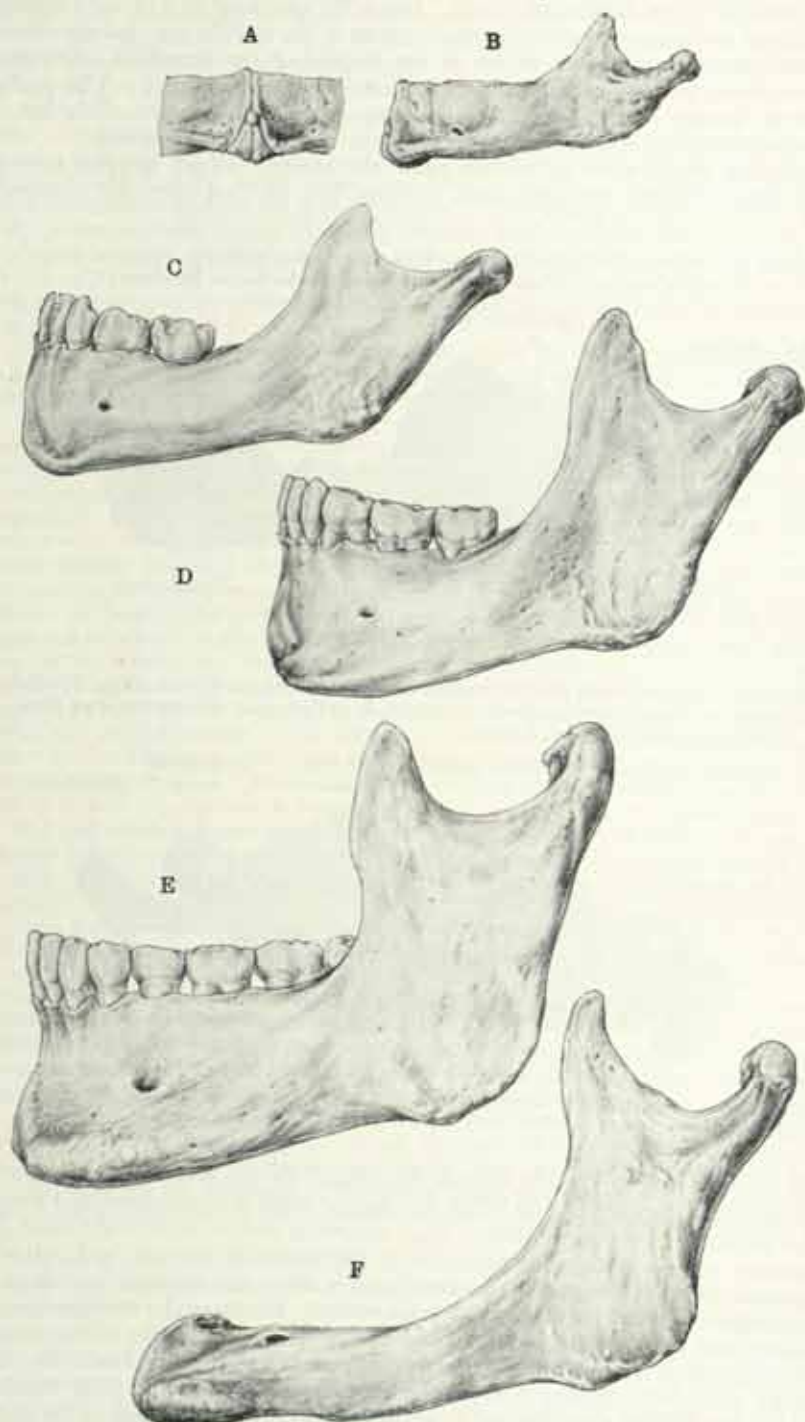
of the primary centres for the clavicle (p. 364). By the tenth week the portion of Meckel's cartilage which lies below the incisor teeth is surrounded and invaded by the membrane-bone. Somewhat later, accessory pieces of cartilage make their appearance—viz. a wedge-shaped piece in the condylar process and extending downwards through the ramus; a small patch along the anterior border of the coronoid process; and smaller nodules elsewhere. The condylar cartilage persists for some years and is mainly responsible for the growth in height of the ramus,† and for the downward and forward growth of the lower part of the face. The other accessory pieces of cartilage undergo absorption. The inner alveolar border is formed in the human mandible by an ingrowth from the main mass of the bone.

* A. Low, *Proceedings of the Anatomical and Anthropological Society of the University of Aberdeen*, 1905, and *Journal of Anatomy and Physiology*, vol. xlv, and E. Fawcett, *Journal of the American Medical Association*, September 2, 1905.

† J. P. Weinman and Harry Sicher, *Bone and Bones*, 1947, Henry Kimpton, London.

A number of small ossicles, termed the *ossicula mentalia*, appear in the fibrous tissue of the symphysis about the seventh month of fetal life (fig. 323 A). They en-

FIG. 323.—The mandible at different periods of life.



large and very soon fuse with one another, and with the mandible, in no fixed order. Usually two or four in number, they are responsible for the formation of the mental protuberance. Whether they ossify in the remains of the ventral ends of Meckel's cartilages or independently of them in the fibrous tissue of the symphysis is uncertain.

THE CHANGES PRODUCED IN THE MANDIBLE BY AGE

At birth (fig. 323 A, B) the bone is in two separate halves united to each other in the median plane by fibrous tissue. This union is usually termed the *symphysis menti*. The body of the bone is a mere shell, enclosing the sockets of the deciduous teeth, imperfectly partitioned off from one another. The mandibular canal runs near the lower border of the bone, and the mental foramen opens below the socket of the first deciduous molar tooth. The coronoid process is relatively large and projects above the level of the condyle.

After birth (fig. 323, C, early in third year: D, sixth year) the two halves of the bone become joined at the symphysis from below upwards, in the first year; but a trace of separation may still be visible in the beginning of the second year, near the alveolar margin. The body elongates, but more especially behind the mental foramen, to provide space for the three additional teeth developed in this part. The depth of the body increases; growth of the alveolar part of the bone affords room for the roots of the teeth, and the subalveolar portion becomes thicker and deeper. After the second dentition the mandibular canal is situated a little above the level of the mylohyoid line, and the mental foramen occupies the position usual to it in the adult. As the mandible increases in size, bone is laid down along the posterior borders of the ramus and the coronoid process, while at the same time absorption of bone is occurring along their anterior borders. This process of remodelling goes on continuously until the bone has reached its adult size, and it enables the alveolar part to lengthen sufficiently to provide the necessary space for the permanent molar teeth.

In the adult (fig. 323, E) the alveolar and subalveolar portions of the body are of about equal depth. The mental foramen opens midway between the upper and lower borders of the bone, and the mandibular canal runs nearly parallel with the mylohyoid line. The angle subtended by the lower border of the body of the mandible to a plane surface which touches the posterior surface of the condyle above and the posterior border of the ramus below, necessarily diminishes as the height of the ramus increases with age, but X-ray photographs of the same child at different ages* show that the contour of the angle of the mandible remains unaltered.

In old age (fig. 323 F) the bone is reduced in size. Following the loss of the teeth the alveolar part is absorbed, and consequently the mandibular canal and the mental foramen are close to the alveolar border. The ramus is oblique in direction, the angle measures about 140° , and the neck of the mandible is more or less bent backwards.† The process of absorption affects chiefly the thinner of the two alveolar walls and, after its completion, a linear *alveolar ridge* is found on the alveolar border of the bone. In the mandible the labial wall is the thinner in the incisor and canine regions, but it is the lingual wall which is the weaker in the molar region. The alveolar ridge lies therefore within the line of the teeth in the incisor region but lies outside that line in the molar region, forming a curve which is wider than the curve of the line of the teeth and intersects it on each side in the premolar region. *In the maxilla, however, the labial wall is everywhere the thinner and, after absorption, the alveolar ridge lies wholly within the curve of the line of the teeth.*

THE HYOID BONE [OS HYOIDEUM]

The **hyoid bone** (fig. 324) is U-shaped and is suspended from the tips of the styloid processes of the temporal bones by the stylohyoid ligaments. It has a body, two greater and two lesser cornua.

The **body** or middle part of the hyoid bone is of a quadrilateral form. Its *anterior surface* is convex and directed forwards and upwards. Its upper part is crossed by a well-marked ridge, which has a slight downward convexity, and in many cases a vertical median ridge divides the body into lateral halves. The portion of the vertical ridge above the transverse line is present in the majority of specimens, but that below the transverse line is rarely seen. The *posterior surface* is smooth,

* A. G. Brodie, *Amer. J. Anat.*, 68, 1941.

† Sir Arthur Keith and G. G. Campion, *Dental Record*, 1922; Arthur Thomson, *Dental Record*, 1924; and Lectures on *The Growth of the Jaws*, by Fawcett, Brash, Northcroft and Keith. Published by the Dental Board of the United Kingdom, 1924.

concave, directed backwards and downwards, and separated from the epiglottis by the thyrohyoid membrane and a quantity of loose areolar tissue; a bursa intervenes between the bone and the membrane. In early life the *lateral extremities* of the body are connected to the greater cornua by primary cartilaginous joints, but after middle life they are usually united by bone.

The **greater cornua** of the hyoid bone project backwards from the lateral limits of the body; they are flattened from above downwards and diminish in size from before backwards. Each cornu ends posteriorly in a tubercle. When the throat is gripped between finger and thumb just above the thyroid cartilage, the greater cornua can be felt in the living subject and the bone can be moved from side to side.

The **lesser cornua** of the hyoid bone are two small, conical eminences attached by their bases at the angle of junction of the body and greater cornua. They are connected to the body of the bone by fibrous tissue and occasionally to the greater cornua by synovial joints, which usually persist throughout life, but occasionally become ankylosed.

Particular features.—The *anterior surface* of the **body** gives insertion to the geniohyoid muscle in the greater part of its extent both above and below the transverse ridge; a portion of the origin of the hyoglossus muscle invades the lateral margin of the geniohyoid area (fig. 325). The lower part of this surface gives insertion to the

FIG. 324.—The hyoid bone. Antero-superior aspect.

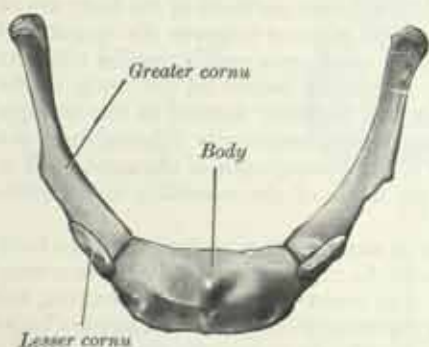
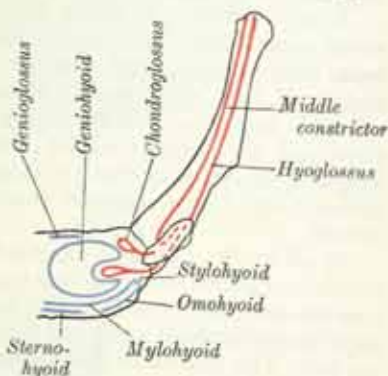


FIG. 325.—A drawing of the left half of the hyoid bone to show the muscular attachments. Viewed from above.



mylohyoid muscle, and below that to the sternohyoid medially and the omohyoid laterally. The *superior border* of the body is rounded and gives attachment to the lowest fibres of the genioglossi, to the hyo-epiglottic ligament and to the thyrohyoid membrane. The *inferior border* gives insertion to the sternohyoid medially and the omohyoid laterally, and sometimes to the medial fibres of the thyrohyoid muscle. It gives attachment also to the levator glandulae thyroideae, when present.

The *upper surface* of the **greater cornu** gives origin to the middle constrictor of the pharynx and, more laterally, to the hyoglossus muscle, both of which extend throughout its whole length. Near the junction of the cornu with the body the stylohyoid muscle is inserted lateral to the hyoglossus muscle, and a little posterior to this insertion the fibrous loop through which the tendon of the digastric muscle runs is attached to the bone. The *medial border* gives attachment to the thyrohyoid membrane; the lateral border receives, anteriorly, the insertion of the thyrohyoid muscle. The inferior surface, which is oblique, is separated from the thyrohyoid membrane by some fibro-areolar tissue.

The posterior and lateral aspects of the **lesser cornu** give origin to fibres of the middle constrictor muscle of the pharynx. Its apex gives attachment to the stylohyoid ligament, which is often ossified in part. The medial aspect of its base gives origin to the chondroglossus muscle.

Ossification.—The hyoid bone is developed from the cartilages of the second and third visceral arches—the lesser cornua from the second, the greater cornua from the third, and the body from the fused ventral ends of both (p. 118). It is ossified from six centres: a pair for the body, and one for each cornu. Ossification commences in the greater cornua towards the end of intrauterine life, in the body before or shortly after birth, and in the lesser cornua during the first or second year, or later.

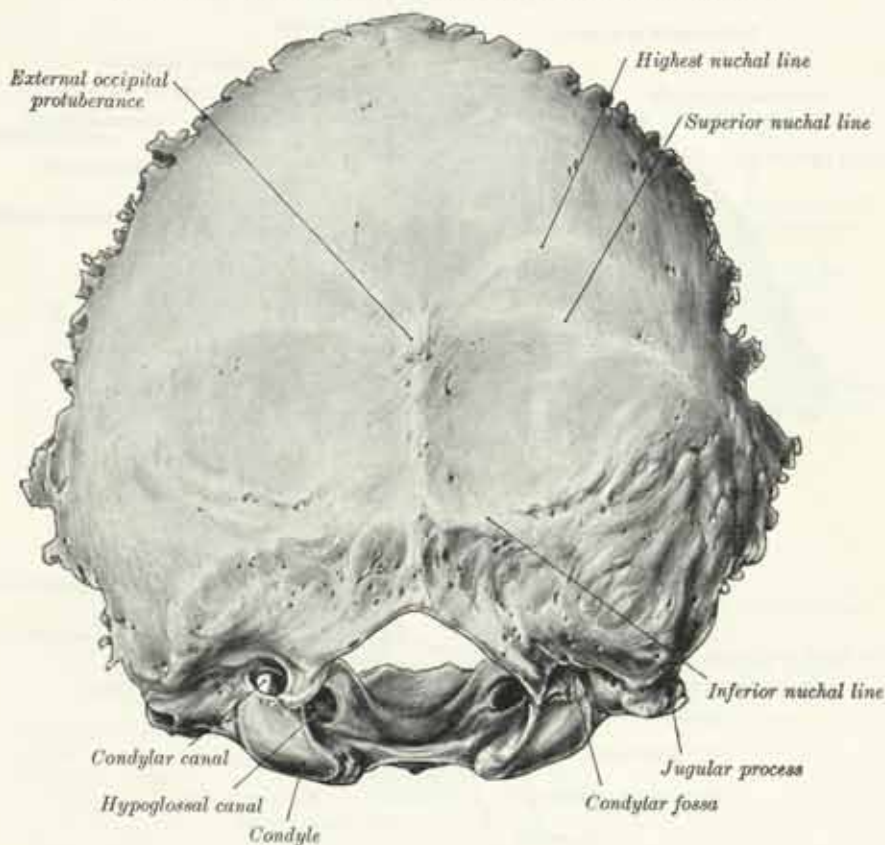
THE CRANIAL BONES

THE OCCIPITAL BONE

The **occipital bone** (figs. 326-328), situated at the posterior and inferior part of the cranium, is trapezoid in shape and concave forwards. It encloses a large oval opening, termed the *foramen magnum*, through which the cranial cavity communicates with the vertebral canal. The expanded plate above and behind this foramen is named the *squamous part*; the thick, somewhat quadrilateral piece in front of it is called the *basilar part*; that on each side of the foramen is named the *lateral (condylar) part*.

The **squamous part** of the occipital bone, situated above and behind the foramen magnum, is curved from above downwards and from side to side.

FIG. 326.—The occipital bone. Posterior aspect.
The condylar canal was present on the left side only in this specimen.



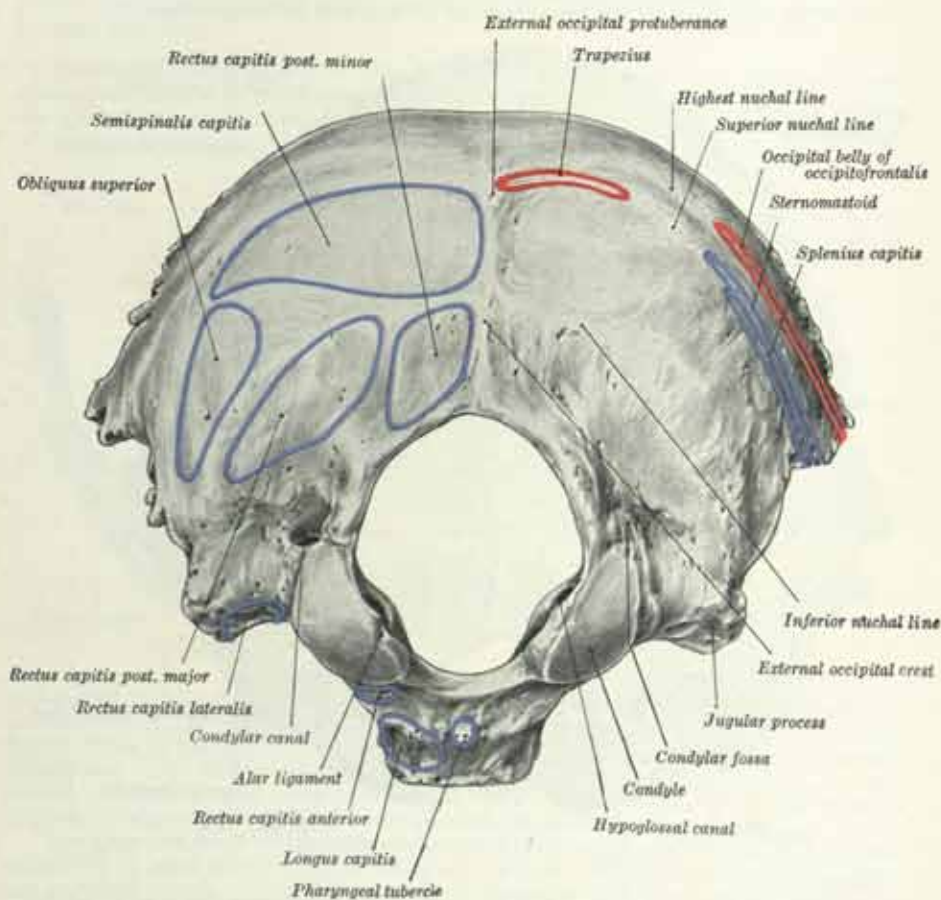
The *external surface* is convex and presents, midway between the summit of the bone and the foramen magnum, a prominence termed the *external occipital protuberance*. On each side two curved lines, one a little above the other, extend laterally from this bony prominence. The upper line, faintly marked and often absent, is named the *highest nuchal line*, and to it the galea aponeurotica (epicranial aponeurosis) is attached. The lower line is termed the *superior nuchal line*. The part of the external surface above the highest nuchal lines is smooth, and covered with the occipital belly of the occipitofrontalis muscle. The part below the highest nuchal lines is rough and irregular for the attachment of several muscles. From the external occipital protuberance a ridge, termed the *external occipital crest*, often faintly marked, descends to the foramen magnum, and affords attachment to the ligamentum nuchæ; on each side the *inferior nuchal line* runs laterally from the midpoint of the crest. The areas of muscular attachments are clearly shown in fig. 327. The posterior atlanto-occipital membrane is attached around the posterolateral part of the foramen magnum, immediately outside the margin of the foramen.

The *internal surface* of the squamous part is deeply concave, and is divided into four fossæ by an irregular elevation, termed the *internal occipital protuberance*. The

upper two fossæ are triangular, and lodge the posterior portions of the occipital lobes of the cerebrum; the lower two are quadrilateral and support the hemispheres of the cerebellum. A wide groove, with raised edges, extends upwards from the protuberance to the superior angle of the bone; it lodges the hinder part of the superior sagittal sinus and is termed the *sagittal sulcus*; to the margins of this sulcus the posterior part of the falx cerebri is attached. A prominent ridge, named the *internal occipital crest*, runs downwards and forwards from the protuberance; it gives attachment to the falx cerebelli, and bifurcates near the foramen magnum; the occipital sinus, which is sometimes duplicated, lies in the attached margin of the falx. At the lower part of the internal occipital crest a small depression is sometimes distinguishable; it is often termed the *vermian fossa*, since it is occupied by part of the inferior vermis

FIG. 327.—The occipital bone. Inferior aspect.

Drawn from the same specimen as fig. 326.



of the cerebellum. On each side a wide *transverse sulcus* extends laterally from the internal occipital protuberance; these sulci accommodate the transverse sinuses, and their margins give attachment to the tentorium cerebelli. The right transverse sulcus is usually larger than the left and is continuous with the sagittal sulcus; but the left may be larger than the right, or the two may be almost equal in size. The position of the *confluence of the sinuses* is indicated by a depression on one or other side of the protuberance.

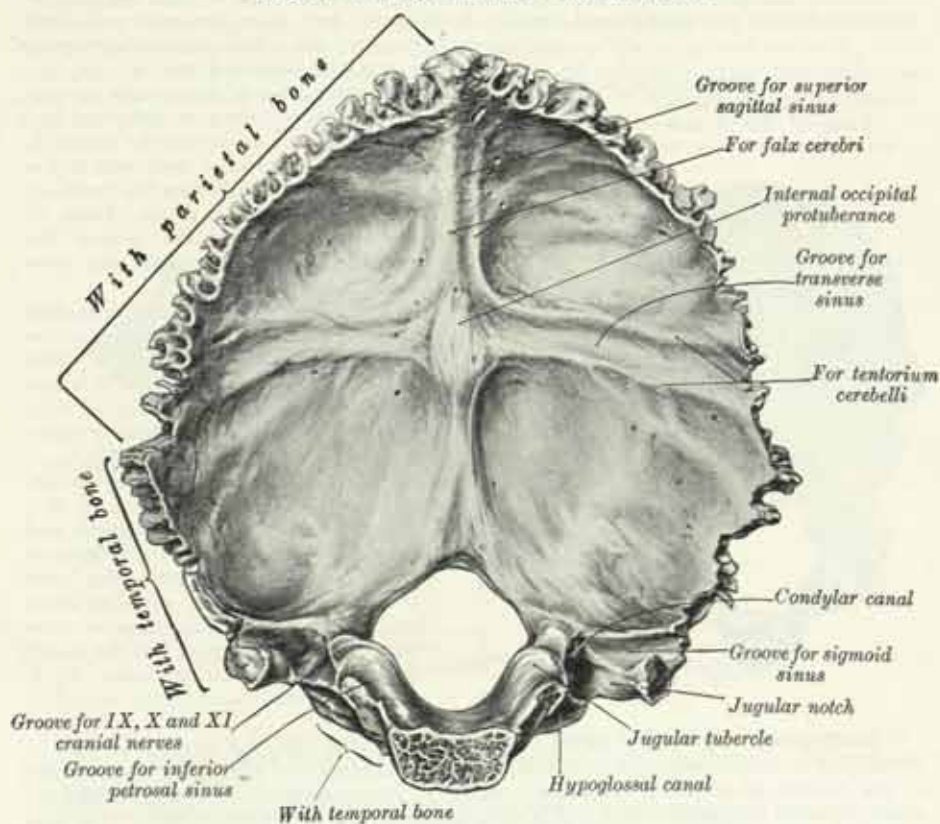
The *superior angle* of the squamous part articulates with the occipital angles of the parietal bones, and corresponds in position with the *posterior fontanelle* of the foetal skull. The *lateral angles* are at the ends of the transverse sulci; each is received into the interval between the parietal bone and the mastoid part of the temporal bone. The *lamboïd borders* extend from the superior to the lateral angles; they are serrated for articulation with the occipital borders of the parietal bones, and by this union form the lamboïd suture. The *mastoid borders* extend from the lateral angles to the jugular processes; each articulates with the mastoid portion of the corresponding temporal bone.

The **basilar part** of the occipital bone extends forwards and upwards from the foramen magnum, and presents *anteriorly* a cut surface, more or less quadrilateral in shape. In the young skull this surface is rough and uneven and is joined to the body of the sphenoid bone by a plate of cartilage. By the twenty-fifth year this plate of cartilage has undergone ossification and the occipital and sphenoid bones are fused.

On the *inferior surface* of the basilar part, about 1 cm. in front of the foramen magnum, a small elevation, termed the *pharyngeal tubercle*, gives attachment to the fibrous raphe of the pharynx. The longus capitis is inserted into the bone lateral to the pharyngeal tubercle, and the rectus capitis anterior into a small depression in front of the occipital condyle. The anterior margin of the foramen magnum gives attachment to the anterior atlanto-occipital membrane.

The *superior surface* of the basilar part consists of a broad, shallow groove, termed the *clivus*, which inclines upwards and forwards from the anterior border of the foramen magnum; it supports the medulla oblongata and the lower part of the pons,

Fig. 328.—The occipital bone. Internal aspect.



and near the margin of the foramen gives attachment to the membrana tectoria and the apical ligament. On the lateral margins of this surface the *inferior petrosal sulci* are occupied by the inferior petrosal sinuses, and below each of these sulci the lateral margin of the basilar part is rough for articulation with the petrous part of the temporal bone.

The **lateral (condylar) parts** of the occipital bone are situated at the sides of the foramen magnum; on their *inferior surfaces* the *occipital condyles* form two oval processes for articulation with the superior facets of the atlas vertebra. They are oval or reniform in shape, with their long axes running forwards and medially, so that their anterior ends are closer together than their posterior and encroach on the basilar portion of the bone; the posterior ends extend back to the level of the middle of the foramen magnum. The articular surfaces of the condyles are convex from before backwards and from side to side; they face downwards and laterally, and are occasionally constricted near their centres. On the medial side of each a rough impression or tubercle gives attachment to the alar ligament. Above the anterior part of each condyle the bone presents the *hypoglossal canal*, which begins on the cranial surface of the bone a short distance above the anterior part of the foramen magnum, and is directed laterally and forwards. It may be partially or completely divided into

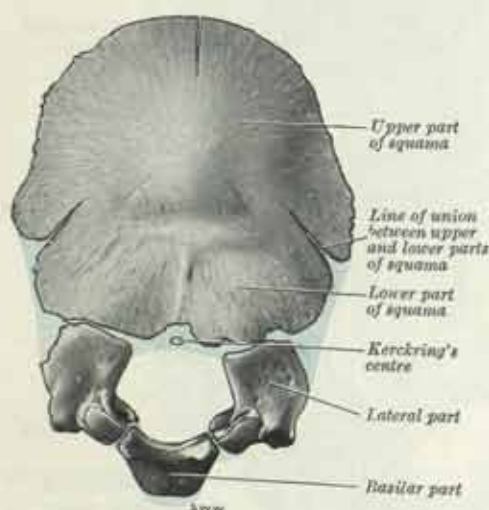
two by a spicule of bone; it gives exit to the hypoglossal nerve, and entrance to a meningeal branch of the ascending pharyngeal artery. A depression, termed the *condylar fossa*, lies behind the condyle and receives the posterior margin of the corresponding superior facet of the atlas when the head is bent backwards; the floor of this fossa is sometimes perforated by the *condylar canal*, through which an emissary vein passes from the sigmoid sinus. The *jugular process* extends laterally from the posterior half of the condyle. It is a quadrilateral plate of bone, indented in front by the *jugular notch*, which, in the articulated skull, forms the posterior part of the jugular foramen. The jugular notch is sometimes divided into two by a bony spicule named the *intrajugular process*, which projects forwards and laterally. The under surface of the jugular process is rough and gives attachment to the rectus capitis lateralis; from this surface an eminence termed the *paramastoid process*, sometimes projects downwards, and may be of sufficient length to articulate with the transverse process of the atlas. Laterally the jugular process presents a rough quadrilateral or triangular area which is joined to the jugular surface of the temporal bone by a plate of cartilage; after the age of twenty-five this plate tends to ossify.

On the *superior surface* of the condylar part an oval eminence, termed the *jugular tubercle*, overlies the hypoglossal canal; its posterior part often presents a shallow furrow for the glossopharyngeal, vagus, and accessory nerves. On the superior surface of the jugular process a deep groove curves medially and forwards around an upwardly directed, hook-shaped process and ends at the jugular notch; it lodges the terminal part of the sigmoid sinus. Close to the medial end of the groove the condylar canal opens into the posterior cranial fossa.

The *foramen magnum* is a large oval opening with its long diameter in the median plane. The foramen is wider behind than in front, where it is encroached upon by the occipital condyles. The structures which it transmits are enumerated on p. 289.

Structure.—The occipital, like the other cranial bones, consists of two compact lamellæ, called the *outer* and *inner plates*, between which there is spongy substance or *diploë*; the bone is thick at the ridges, protuberances and condyles, and at the anterior portion of the basilar part; in the lower parts of the inferior fossæ it is thin, semi-transparent, and devoid of diploë.

FIG. 329.—The occipital bone of a new-born child. External surface.
Parts of the chondrocranium still unossified are shown in blue.



Ossification (fig. 329).—Above the highest nuchal line the squamous part is developed in membrane, and is ossified from two centres, one appearing on each side of the median plane about the second month of intrauterine life; this part may remain separate throughout life, and is then known as the *interparietal bone*. The rest of the occipital bone is preformed in cartilage. Below the highest nuchal line, the squamous part is ossified from two centres, which appear about the seventh week of intrauterine life and soon unite to form a single piece. Union of the upper and lower portions of the squamous part takes place in the third month of intrauterine life, but their line of union can be recognised in the bone at birth (fig. 329). An occasional centre appears in the posterior margin of the foramen magnum about the sixteenth week (Kerckring); it unites with the rest of the squamous part before birth. Each of the lateral parts ossifies from a single centre, which appears during the eighth week of intrauterine life. The basilar portion is ossified from one centre which appears about the sixth week of intrauterine life. About the end of the second year the squamous part unites with the lateral portions, and by the sixth year the bone consists of a single piece. Between the eighteenth and twenty-fifth years the occipital and sphenoid bones unite to form a single bone.

THE SPHENOID BONE

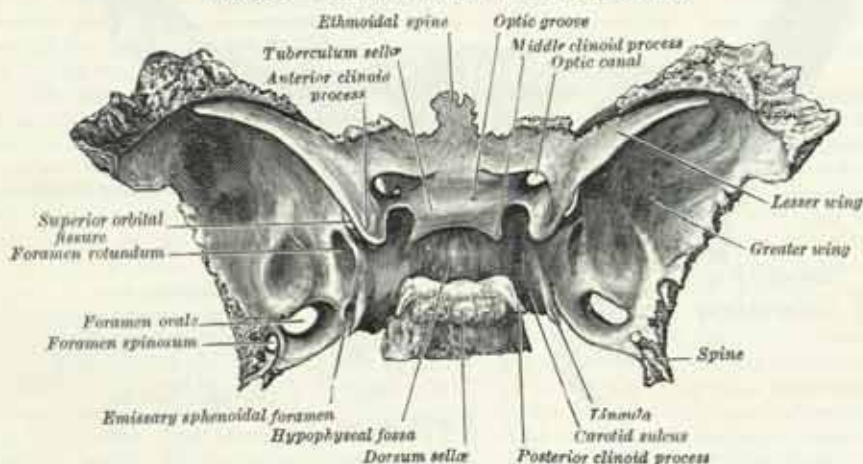
The **sphenoid bone** (figs. 330 to 332) is situated at the base of the skull, in front of the temporal bones and the basilar part of the occipital bone. In shape it resembles a

bat with wings outstretched, and consists of a central portion or body, two greater and two lesser wings, which pass laterally from the sides of the body, and two pterygoid processes, which are directed downwards from the adjoining parts of the body and greater wings.

The **body** of the sphenoid bone is more or less cubical in shape; it contains two large air-sinuses, which are separated from each other by a septum.

The **cerebral or superior surface** of the body (fig. 330) articulates in front with the cribriform plate of the ethmoid bone. Anteriorly the surface is smooth and is termed the *jugum sphenoidale*; it supports the posterior ends of the gyri recti and the olfactory tracts. It is bounded behind by a ridge, which forms the anterior border of a transverse groove, termed the *optic groove*; this sulcus leads laterally to the *optic canal* on each side. Posterior to the groove there is a more or less oval elevation, termed the *tuberculum sellæ*; and behind this a deep depression, termed the *sella turcica*, the deepest part of which lodges the hypophysis cerebri and is known as the *hypophyseal fossa*. The anterior boundary of the *sella turcica* is completed laterally by two small eminences, called the *middle clinoid processes*, whilst the posterior boundary is formed by a square plate of bone, termed the *dorsum sellæ*; the superior angles of this plate end in two tubercles, termed the *posterior clinoid processes*, which vary considerably in form and size and give attachment to the fixed margin of the tentorium cerebelli. On each side of the body below the *dorsum sellæ* a small projection articulates with the apex of the petrous portion of the temporal bone and is often termed the *petrosal process*.

FIG. 330.—The sphenoid bone. Superior surface.



The sloping area behind the *dorsum sellæ* is termed the *clivus*, and is uninterruptedly continuous with the *clivus* of the occipital bone in the adult skull; it supports the upper part of the pons.

The **lateral surfaces** of the body are united with the greater wings and with the medial pterygoid plates. Above the attachment of each wing a broad groove, termed the *carotid sulcus*, forms a curve somewhat like the italic letter *f*; it lodges the internal carotid artery and the cavernous sinus. The *carotid sulcus* is deepest at its posterior end, where it is overhung medially by the petrosal process, and is limited laterally by a sharp margin called the *lingula*; the latter is continued backwards to overlie the posterior opening of the pterygoid canal.

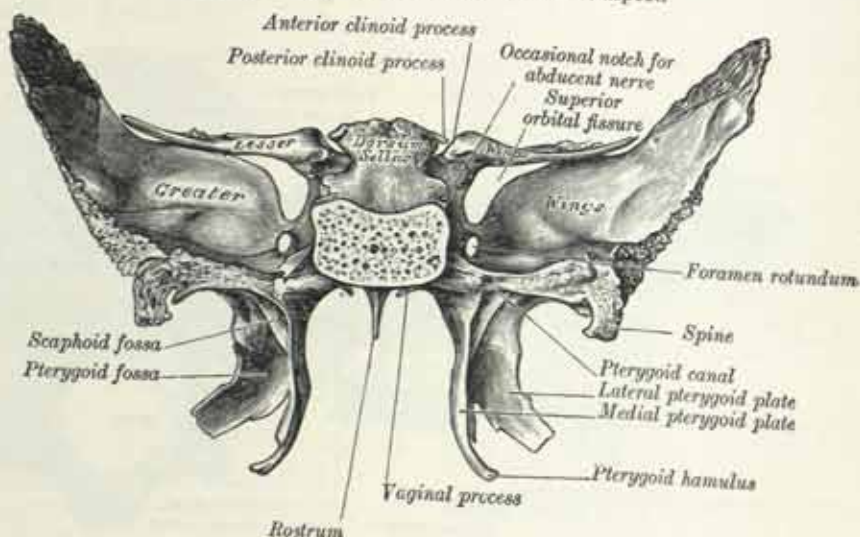
The **anterior surface** of the body (fig. 332) presents, in the median plane, a triangular crest, which forms a small part of the septum of the nose and is termed the *sphenoidal crest*. The anterior border of this crest articulates with the perpendicular plate of the ethmoid bone. On either side of the crest a rounded opening leads into the corresponding *sphenoidal sinus*. The sphenoidal sinuses are two large, irregular cavities in the body of the bone, separated from each other by a bony septum which is commonly bent to one side or the other. They vary considerably in form and size,*

* Logan Turner (*The Accessory Sinuses of the Nose*, 1901) gives the following measurements for an adult sphenoidal sinus of average size: height, 2 cm.; breadth, 1.8 cm.; anteroposterior depth, 2.1 cm. Onodi (*The Accessory Sinuses of the Nose in Children*, 1911) states that in the new-born infant their height is 4 mm. and their width 2 mm., while at the eighth year of life their height is from 8 to 12 mm. and their width 11 mm.

are seldom symmetrical, and are often partially subdivided by bony laminae. A lateral recess may extend from one or other sinus into the greater wing and lingula; * the sinuses occasionally reach into the basilar part of the occipital bone nearly as far as the foramen magnum. In the articulated skull they are closed in front and below by the *sphenoidal conchæ* (p. 318), but a round opening is left in the anterior wall of each sinus, by which it communicates with the sphenoidal recess of the nasal cavity, and occasionally with the posterior ethmoidal sinuses. Each half of the anterior surface of the body of the sphenoid bone consists of two parts: (a) an upper and lateral depressed area, which articulates with the labyrinth of the ethmoid bone and completes the posterior ethmoidal sinuses; its lateral margin articulates with the orbital plate of the ethmoid bone above, and with the orbital process of the palatine bone below; (b) a lower and medial, smooth, triangular area, which forms the posterior part of the roof of the nose; near its superior angle it is pierced by the orifice of the sphenoidal sinus.

The *inferior surface* of the body presents in the median plane a triangular spine, termed the *sphenoidal rostrum* (fig. 332), which, in the articulated skull, projects into a deep fissure between the anterior parts of the alæ of the vomer. The posterior, triangular parts of the sphenoidal conchæ extend backwards on the sides of the rostrum, and articulate with the alæ of the vomer. On each side of the posterior part of the

FIG. 331.—The sphenoid bone. Posterior aspect.



rostrum, and immediately behind the apex of the sphenoidal concha, a thin lamina, named the *vaginal process*, projects medially from the base of the medial pterygoid plate (fig. 332).

The **greater wings** are two strong processes which curve upwards and laterally from the sides of the body. The posterior part of each is triangular and fits into the angle between the petrous portion of the temporal bone and the squamous part (fig. 307) forming the sphenosquamosal suture.

The *cerebral surface* of the greater wing (fig. 330) forms part of the floor of the middle fossa of the skull; it is deeply concave and presents depressions corresponding with the convolutions of the anterior part of the temporal lobe of the brain. At its anteromedial part the *foramen rotundum* gives passage to the maxillary nerve. Behind and lateral to this foramen the *foramen ovale* transmits the mandibular nerve, the accessory meningeal artery, and sometimes the lesser petrosal nerve.† Medial to the foramen ovale, a small aperture, termed the *emissary sphenoidal foramen*, is present on one or both sides in nearly 40 per cent. of skulls; it opens below at the lateral side of the scaphoid fossa and transmits a small vein from the cavernous sinus.

* V. Z. Cope (*Journal of Anatomy and Physiology*, vol. li, part ii.) found a well-marked lateral recess in 72 out of 292 sinuses examined, and pointed out that the hypophysis cerebri, the anterior part of the internal carotid artery, the optic and maxillary nerves, and the nerve of the pterygoid canal may give rise to elevations in the walls of the sinuses.

† The lesser petrosal nerve may pass through a special canal (*canaliculus innominatus*) on the medial side of the foramen spinosum.

In the posterior angle, anteromedial to the spine, there is a short canal, termed the *foramen spinosum*, which transmits the middle meningeal artery and the meningeal branch of the mandibular nerve (*nervus spinosus*) (see also pp. 287 and 295).

The *lateral surface* of the greater wing (fig. 306) is convex from above downwards, and is divided by a transverse ridge, termed the *infratemporal crest*, into an upper or temporal and a lower or infratemporal surface. The *temporal surface*, concave from before backwards, forms a portion of the temporal fossa and gives origin to a part of the temporalis muscle. The *infratemporal surface* is concave and directed downwards; together with the infratemporal crest, it gives origin to the upper head of the lateral pterygoid muscle. It is pierced by the *foramen ovale* and *foramen spinosum*, and its posterior part bears the *spine of the sphenoid bone* (p. 285), which forms a small, sometimes pointed process, projecting downwards. Its medial side is usually marked by a faint groove, directed downwards and forwards, for the chorda tympani nerve (p. 1118), and helps to form the lateral wall of the sulcus for the auditory tube (p. 285). Its tip gives attachment to the sphenomandibular ligament. Medial to the anterior extremity of the infratemporal crest a triangular process serves to increase the attachment of the lateral pterygoid muscle. A ridge runs downwards and medially from this triangular process to the front of the lateral pterygoid plate; it forms the posterior boundary of the pterygopalatine fissure.

The *orbital surface* of the greater wing (fig. 332), quadrilateral in shape, is directed forwards and medially and forms the posterior part of the lateral wall of the orbit. Its upper, serrated edge articulates with the orbital plate of the frontal bone; its lateral, serrated margin with the zygomatic bone. Its inferior smooth border forms the posterolateral boundary of the inferior orbital fissure. Its medial sharp margin constitutes the lower, or lateral, boundary of the superior orbital fissure, and from it a small tubercle projects and gives attachment to part of the anulus tendineus communis, from which the rectus muscles of the eyeball take origin. Below the medial end of the superior orbital fissure there is a grooved area which forms the posterior wall of the pterygopalatine fossa and is pierced by the foramen rotundum.

The *margin of the greater wing* (fig. 332).—The portion of the margin of the greater wing which extends from the body to the spine of the sphenoid is irregular. Its medial half forms the anterior boundary of the *foramen lacerum* and presents the posterior aperture of the pterygoid canal for the passage of the corresponding nerve and artery. Its lateral half articulates with the petrous portion of the temporal bone, by means of a cartilaginous joint, which is termed the *sphenopetrosal synchondrosis*. Between the two bones, on the under surface of the skull, there is a furrow, named the *sulcus tubæ*, which lodges the cartilaginous part of the auditory tube. Extending forwards from the sphenoidal spine the *squamosal margin* forms a concave, serrated edge, bevelled at the expense of the inner surface below and of the outer surface above, for articulation with the squamous part of the temporal bone. The tip of the greater wing is bevelled at the expense of the inner surface and articulates with the sphenoidal angle of the parietal bone at the *pterion*. Medial to this, there is a triangular rough area, for articulation with the frontal bone; the medial angle of this area is continuous with the sharp edge which forms the lower boundary of the superior orbital fissure, and the anterior angle with the serrated margin for articulation with the zygomatic bone.

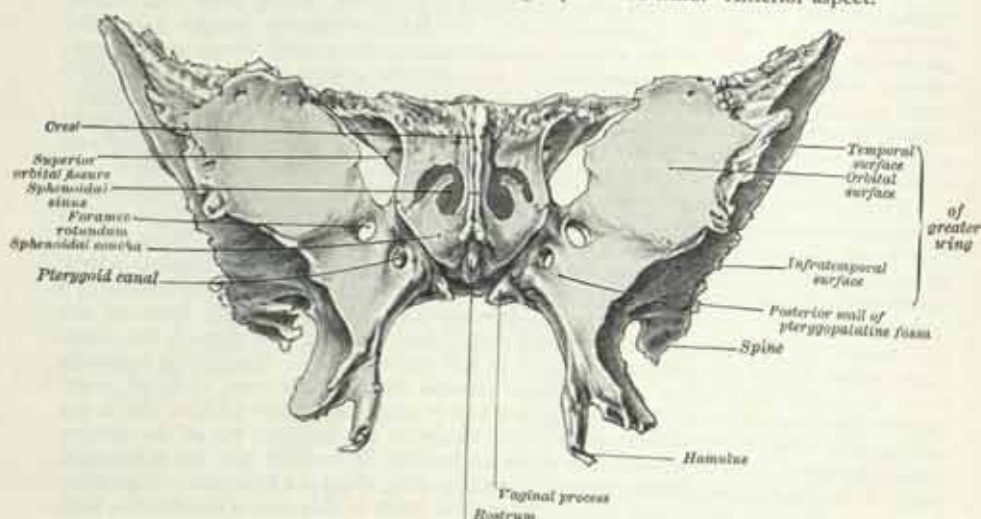
The *lesser wings* of the sphenoid bone are two triangular plates which project laterally from the upper and anterior parts of the body and end in sharp points (figs. 330, 331). The *cerebral surface* of each is smooth, and supports a small part of the frontal lobe of the brain. The *inferior surface* forms the posterior part of the roof of the orbit and the upper boundary of the *superior orbital fissure*; it overhangs the anterior part of the middle fossa of the skull. The *anterior border* of the lesser wing is serrated for articulation with the posterior edge of the orbital plate of the frontal bone. The *posterior border* is smooth and projects into the lateral cerebral fissure; the medial end of this border forms the *anterior clinoid process*, which gives attachment to the anterior end of the free border of the tentorium cerebelli. The anterior and middle clinoid processes are sometimes united by a spicule of bone, and when this occurs the end of the groove for the internal carotid artery is converted into a foramen (*caroticoclinoid foramen*). The lesser wing is connected to the body by two roots, the anterior thin and flat, the posterior thick and triangular; the *optic canal* which lies between them, transmits the optic nerve and ophthalmic artery.

The *superior orbital fissure* is triangular in shape and leads from the cranial cavity into the orbit; it is bounded medially by the body of the sphenoid bone; above, by the lesser wing; below, by the medial margin of the orbital surface of the greater wing; and is completed laterally, between the greater and lesser wings, by the frontal bone. It transmits to the orbit the oculomotor, trochlear and abducent nerves, the three branches of the ophthalmic division of the trigeminal nerve, the orbital branch of the middle meningeal artery, and some filaments from the internal carotid plexus of the sympathetic; and from the orbit the recurrent meningeal branch of the lacrimal artery, and the ophthalmic veins.

The **pterygoid processes** of the sphenoid (figs. 331, 332), one on each side, descend perpendicularly from the regions where the greater wings unite with the body. Each process consists of a medial and a lateral plate, the upper parts of which are fused anteriorly. The plates are separated below by an angular cleft, termed the *pterygoid fissure*; the rough margins of which articulate with the pyramidal process of the palatine bone. The two plates diverge behind, and the wedge-shaped *pterygoid fossa* between them contains the medial pterygoid and tensor veli palatini muscles. Above this fossa there is a small, oval, shallow depression, named the *scaphoid fossa*, which is formed by the division of the upper part of the posterior border of the medial pterygoid plate; it gives origin to part of the tensor veli palatini muscle. The anterior surface of the pterygoid process is broad and triangular near its root, where it forms the posterior wall of the pterygopalatine fossa; it is pierced by the anterior orifice of the *pterygoid canal*.

The *lateral pterygoid plate* is broad, thin, and everted; its *lateral surface* forms part of the medial wall of the infratemporal fossa and gives origin to the lower head of the lateral pterygoid; its *medial surface* forms the lateral wall of the pterygoid fossa and gives origin to the greater part of the medial pterygoid muscle. The upper part of the *anterior border* forms the posterior boundary of the pterygopalatine fissure; the lower part articulates with the palatine bone; its *posterior border* is free.

FIG. 332.—The sphenoid bone of an eight years old child. Anterior aspect.



The *medial pterygoid plate* is narrower and longer than the lateral; its lower extremity curves laterally into a hook-like process, termed the *pterygoid hamulus*, around which the tendon of the tensor veli palatini glides, and to which the pterygo-mandibular raphe is attached. The *lateral surface* of this plate forms the medial wall of the pterygoid fossa, and the tensor veli palatini lies against it; the *medial surface* constitutes the lateral boundary of the corresponding posterior nasal aperture. Superiorly the medial pterygoid plate is prolonged on to the under surface of the body as a thin lamina, named the *vaginal process*, which articulates anteriorly with the sphenoidal process of the palatine bone and medially with the ala of the vomer. On its under surface there is a furrow, the anterior part of which is converted into a canal by the sphenoidal process of the palatine bone; this canal is named the *palatinovaginal canal*, and transmits the pharyngeal branch of the maxillary artery and the pharyngeal nerve from the pterygopalatine ganglion. The posterior margin of the medial pterygoid plate gives attachment in its entire length to the pharyngobasilar fascia, and from the lower end of this margin the superior constrictor muscle of the pharynx takes origin. The upper end of this margin is marked by a small projection, often named the *pterygoid tubercle*, which lies immediately below the posterior opening of the pterygoid canal. Projecting backwards from near the middle of the margin is an angular process, sometimes termed the *processus tubarius*, which supports the pharyngeal end of the auditory tube. The lower part of the anterior margin of the medial pterygoid plate articulates with the posterior border of the perpendicular plate of the palatine bone.

The **sphenoidal conchæ** (fig. 332) are two thin, curved plates, situated at the anterior and lower parts of the body of the sphenoid bone; the upper, concave surface of each forms the anterior wall and a part of the floor of the corresponding

sphenoidal sinus. The sphenoidal conchæ are usually more or less destroyed in the process of disarticulating the skull, but, when seen *in situ* each consists of an anterior vertical, quadrilateral part and a posterior, horizontal, triangular part. The anterior, vertical portion consists of (a) an upper and lateral depressed area, which completes the posterior ethmoidal sinuses and articulates below with the orbital process of the palatine bone; and (b) a lower and medial area, smooth and triangular, which forms part of the roof of the nasal cavity, and is perforated above by a round opening through which the sphenoidal sinus communicates with the sphenoidal recess of the nasal cavity. The anterior vertical portions of the two bones meet in the median plane and are protruded forwards as the sphenoidal crest. The horizontal triangular portion of the concha forms a part of the roof of the nasal cavity and completes the sphenopalatine foramen; its medial margin articulates with the rostrum of the sphenoid and with the ala of the vomer; its apex, directed backwards, lies medial to and above the vaginal process of the medial pterygoid plate, and articulates with the posterior part of the ala of the vomer. A small piece of the sphenoidal concha sometimes appears in the medial wall of the orbit, between the orbital plate of the ethmoid in front, the orbital process of the palatine bone below, and the frontal bone above.

Ossification.—Until the seventh or eighth month of intrauterine life the body of the sphenoid consists of two parts—viz. one in front of the tuberculum sellæ, forming the *presphenoidal part*, with which the lesser wings are continuous; the other comprising the sella turcica and dorsum sellæ, forming the *postsphenoidal part*, with which the greater wings and pterygoid processes are associated. A considerable part of the bone is preformed in cartilage. There are six centres for the presphenoidal and eight for the postsphenoidal part.

Presphenoidal part.—About the ninth week a centre of ossification appears for each of the lesser wings, just lateral to the optic canal; shortly afterwards two centres appear in the presphenoidal part of the body. The sphenoidal conchæ are each developed from a centre which appears in the fifth month of intrauterine life in the upper and posterior part of the nasal capsule. As the centre enlarges it partially surrounds a small backward expansion of the upper and posterior part of the nasal cavity, which subsequently becomes the sphenoidal sinus. The posterior wall of the concha becomes absorbed, allowing the sinus to invade the presphenoid. In the fourth year the concha fuses with the ethmoidal labyrinth, and before puberty it fuses with the sphenoid and palatine bones. The deficiency in its anterior wall persists as the opening of the sphenoidal sinus.

Postsphenoidal part.—The first centres of ossification are those for the greater wings. About the eighth week one appears below the foramen rotundum in the cartilage which forms the base of each wing. This centre forms only the root of the greater wing in the neighbourhood of the foramen rotundum and the pterygoid canal. The whole of the rest of the greater wing is ossified in membrane and the process extends downwards into the lateral pterygoid plate (Fawcett). About the fourth month, two centres appear in the postsphenoidal part of the body, one on each side of the sella turcica, and soon fuse. Each medial pterygoid plate is ossified in membrane, and its centre probably appears about the ninth or tenth week; the hamulus is *chondrified* during the third month and almost at once begins to ossify.* The medial and lateral pterygoid plates join about the sixth month. About the fourth month a centre appears for each lingula and speedily joins the rest of the bone.

The presphenoidal and the postsphenoidal parts of the body fuse about the eighth month of intrauterine life, but a wedge-shaped piece of cartilage persists for some time after birth in the lower part of the line of fusion. At birth the bone is in three pieces (fig. 333): a central, consisting of the body and lesser wings, and two lateral, each comprising a greater wing and pterygoid process. In the first year after birth the greater wings and body unite around the margins of the pterygoid canal, and the lesser wings extend medially above the anterior part of the body and meet to form an elevated smooth surface, termed the *jugum sphenoidale*. By the twenty-fifth year the sphenoid and occipital bones are completely fused. In the *anterior part* of the hypophyseal fossa there is occasionally a vascular foramen, which is usually, but erroneously, termed the *craniopharyngeal canal*.†

As already indicated, the sphenoidal sinus is present before birth as an extension of the nasal cavity into the sphenoidal concha. In the second or third year it extends backwards into the presphenoid and subsequently invades the postsphenoid, reaching its full, normal, size in adolescence. As age advances it frequently under-

* E. Fawcett, *Anatomischer Anzeiger*, March 1905.

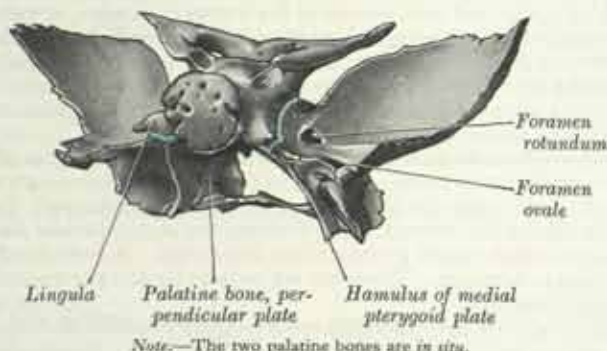
† According to L. B. Arey (see footnote on p. 186), the so-called craniopharyngeal canal in the adult is a vascular channel, bearing no relation to the embryonic stalk of the anterior lobe of the hypophysis, which disappears entirely before the end of the eighth week.

goes a further enlargement, associated with absorption of its bony walls (see also p. 316, footnote).

Certain parts of the sphenoid bone are connected by ligaments which occasionally ossify. The more important of these ligaments are: the *pterygospinous*, stretching between the spine of the sphenoid and the upper part of the lateral pterygoid plate (see *cervical fascia*); the *interclinoid*, joining the anterior to the posterior clinoid process; and the *caroticoclinoid*, connecting the anterior to the middle clinoid process.

FIG. 333.—The sphenoid bone at birth. Viewed from behind and from the right side.

The blue strip indicates the cartilage between the central and the lateral portion on the right side; only a small portion of it is visible on the left side.



Note.—The two palatine bones are in situ.

Applied Anatomy.—Premature ossification or synostosis of the suture between the pre- and postsphenoidal parts (which normally begin to join at the eighth month) and of the sphenoccipital suture produces a characteristic physiognomy. This is best seen in profile, and consists in an abnormal depression of the bridge of the nose; it is a feature often observed in dwarfs.

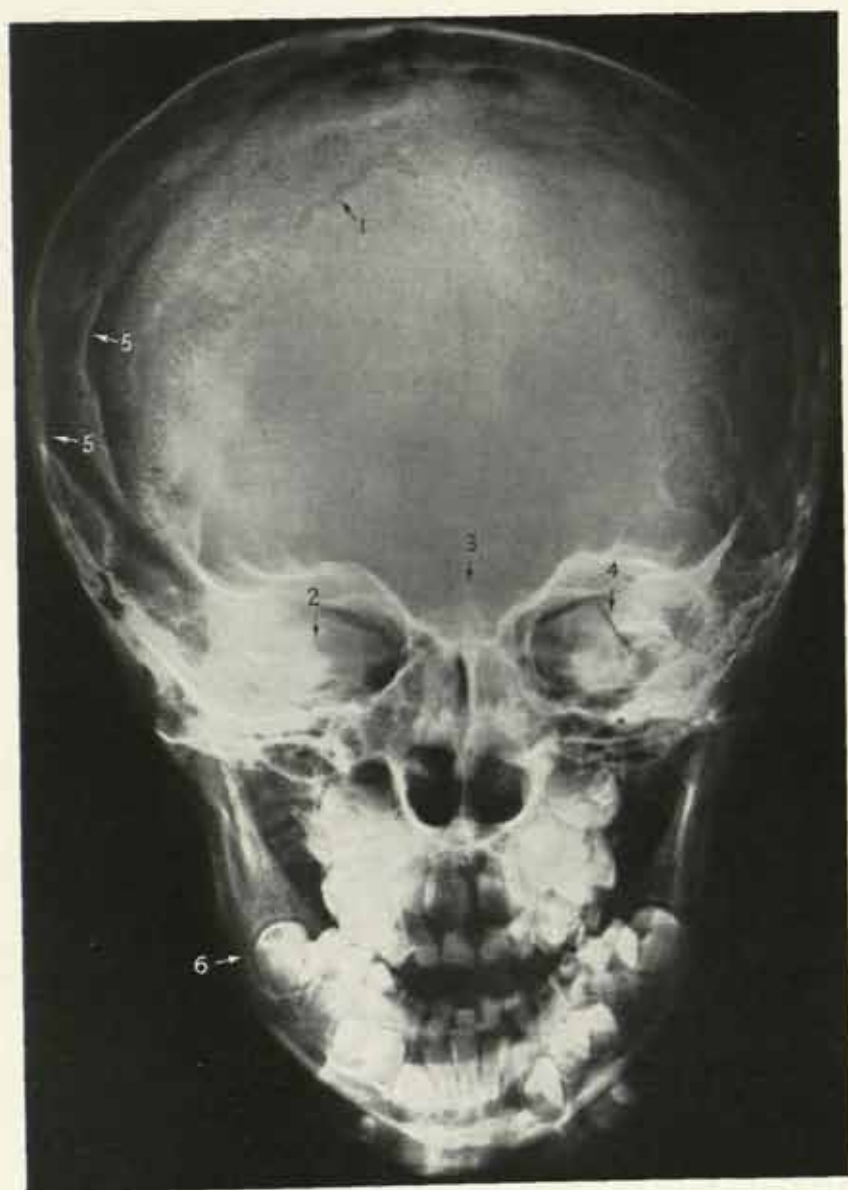
THE TEMPORAL BONES

The **temporal bones** are situated at the sides and base of the skull. Each consists of four parts, viz. the *squamous*, *petromastoid*, and *tympanic parts*, and the *styloid process*. These represent four morphologically distinct elements which have become fused with one another. The squamous part is a dermal bone developed to assist in the protection of the cerebrum. The petromastoid portion is preformed in cartilage as a protecting capsule for the membranous labyrinth. The tympanic part, formed in membrane, is homologous with the angular bone, which constitutes a part of the composite lower jaw of many reptilians and bony fishes; it has become incorporated in the skull and adapted to play a part in the provision of a satisfactory mechanism for the transmission of sound-waves in an air medium. The styloid process represents the dorsal end of the skeletal element of the hyoid arch. The fusion of these distinct elements to form the temporal bone and the inclusion of the tympanic cavity within the bone during the process have been dealt with on p. 151.

The **squamous part** of the temporal bone forms the anterior and upper part of the bone, and is scale-like, thin and translucent. Its *temporal surface* (fig. 334) is smooth and slightly convex; it forms part of the temporal fossa and gives origin to the temporal muscle; above the opening of the external acoustic meatus it is marked by a vertical groove for the middle temporal artery. A curved line, often termed the *supramastoid crest*, courses backwards and upwards across its posterior part; it serves for the attachment of the temporal fascia and limits the origin of the temporal muscle. The boundary between the squamous and mastoid portions of the bone lies about 1.5 cm. below the supramastoid crest and is frequently indicated by traces of the original squanomastoid suture. Between the anterior end of the supramastoid crest and the posterosuperior sector of the opening of the external acoustic meatus there is a depression, often termed the *suprameatal triangle*; this triangle is an important landmark for the mastoid antrum, which lies medial to it, at a depth of about 1.25 cm. The anterior part of the depression is usually marked by a small projection, termed the *suprameatal spine*.

A long, arched process, termed the *zygomatic process*, or *zygoma*, projects forwards from the lower portion of the temporal surface. The posterior part of this process is triangular in shape and springs from a broad base; it is directed laterally, and its surfaces are superior and inferior. The process is then twisted forwards and medially, and the surfaces of its anterior portion are therefore medial and lateral. The superior

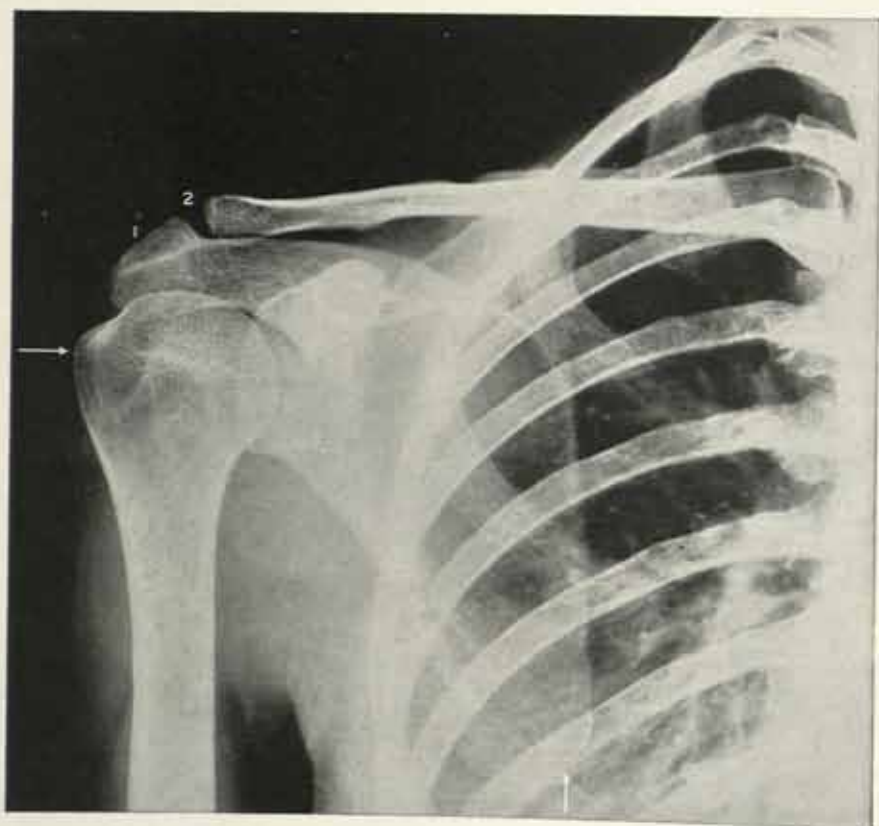
PLATE V



Radiograph of child's skull, aged 7. Occipito-frontal view.

1. Lambdoid suture. 2. Petrous portion of right temporal bone, seen through the cavity of the orbit. 3. Crista galli of the ethmoid bone. 4. Fracture through petrous portion of left temporal bone, seen through the cavity of the orbit. 5. Impressions for cerebral gyri. 6. Second permanent molar tooth, not yet erupted.

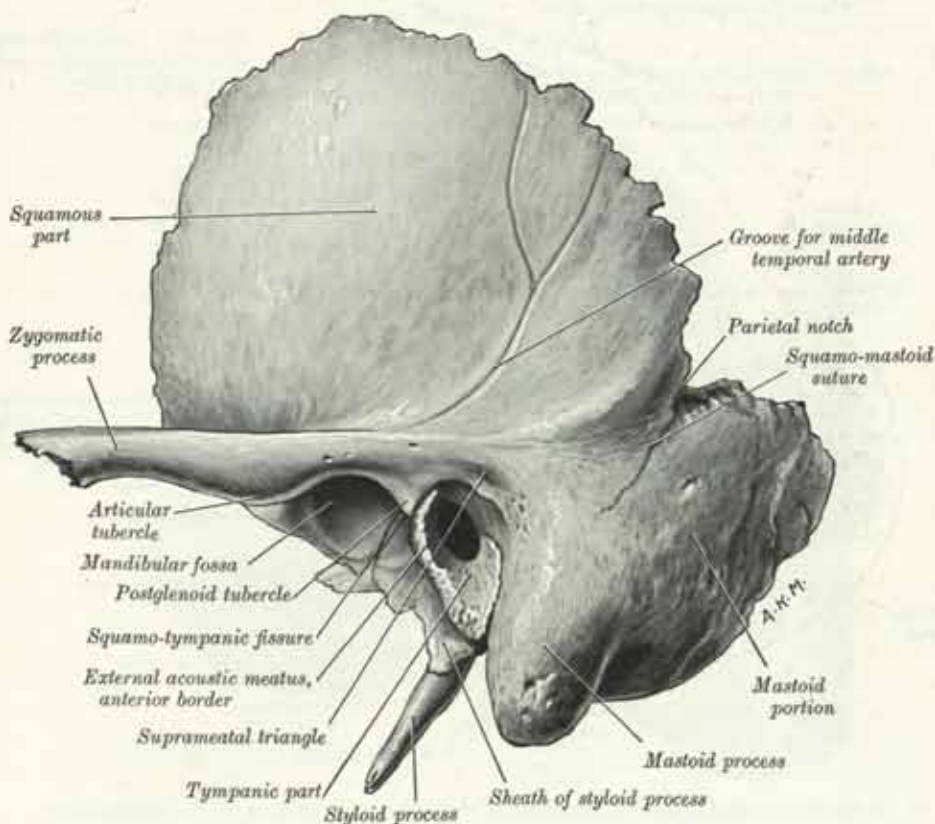
PLATE VI



Radiograph of an adult shoulder. 1 = acromion ; 2 = acromio-clavicular joint. The lower arrow indicates the inferior angle of the scapula, the upper arrow the greater tubercle. Note that the shadow of the head of the humerus overlaps the shadow of the acromial angle and a part of the glenoid cavity.

surface of the posterior part is concave, and continuous with the temporal surface of the squamous part; the inferior surface is bounded by two roots, a *posterior* and an *anterior*, which converge as they approach the anterior part of the process. At the meeting point of the two roots the *tubercle of the root of the zygoma* gives attachment to the lateral ligament of the temporomandibular joint. The posterior root is prolonged forwards from the surface of the squamous part immediately above the opening of the external acoustic meatus; its upper border is continuous behind with the supramastoid crest. The anterior root juts almost horizontally from the side of the squamous part; its inferior surface, convex from before backwards, is smooth for articulation with the articular disc of the temporomandibular joint, and the whole root presents the form of a short semicylindrical bar, named the *articular tubercle*, which forms the anterior boundary of the mandibular fossa. Very rarely the squamous

FIG. 334.—The left temporal bone. External aspect.

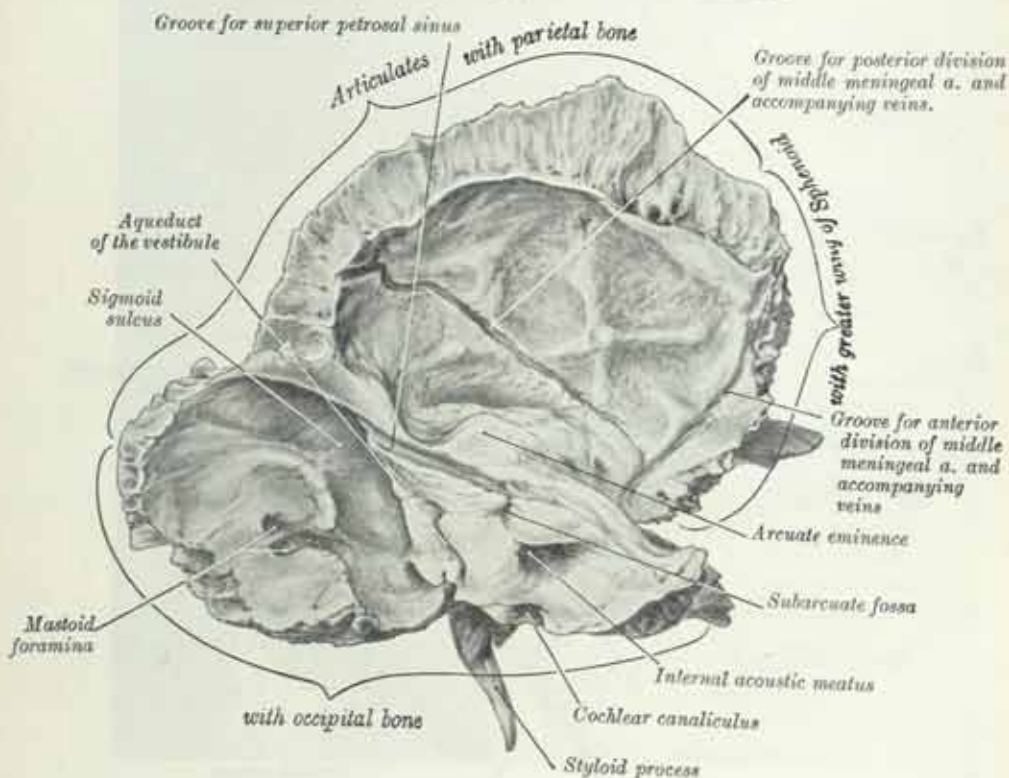


part is perforated just above the posterior root of the zygoma. When present, this *squamosal foramen* transmits the petrosquamous sinus (p. 849).

The anterior part of the zygomatic process is thin and flat. The superior border, long and thin, gives attachment to the temporal fascia; the inferior, short and arched, gives origin to some fibres of the masseter muscle. The lateral surface is convex and subcutaneous; the medial is concave and gives origin to part of the masseter. The anterior end is deeply serrated and cut obliquely at the expense of the lower border; it articulates with the temporal process of the zygomatic bone. In front of the articular tubercle a small triangular area forms a part of the roof of the infratemporal fossa and is separated from the temporal surface of the squamous part by a ridge; this ridge is continuous behind with the anterior root of the zygomatic process, and in front, in the articulated skull, with the infratemporal crest on the greater wing of the sphenoid bone. The *mandibular fossa* is bounded in front by the articular tubercle; it consists of an anterior, articular portion, formed by the squamous part of the temporal bone, and a posterior, non-articular portion, formed by the tympanic part. The articular surface, smooth, oval and deeply concave, articulates with the articular disc of the temporomandibular joint; the non-articular portion sometimes lodges a small part of the parotid gland. A small, conical eminence, often termed the *postglenoid tubercle*, separates the lateral part of the articular surface from the anterior margin of the tym-

panic part of the bone, and is the representative of a prominent tubercle which, in some mammals, descends behind the condyle of the mandible and prevents its backward displacement; the postglenoid tubercle is sometimes described as the third root of the zygomatic process. The medial part of the articular portion of the fossa is separated from the tympanic part of the bone by the *squamotympanic fissure*, into which projects the lower edge of the downturned anterolateral part of the tegmen tympani of the petrous part of the bone; the *petrotympanic fissure* is situated between this plate and the tympanic part. This fissure leads into the middle ear or tympanic cavity; it lodges the anterior ligament of the malleus and transmits the anterior tympanic branch of the maxillary artery. The medial end of the fissure presents the anterior opening of the *anterior canaliculus for the chorda tympani*. Very rarely a *postglenoid foramen* is present just in front of the external acoustic meatus and in the line of fusion

FIG. 335.—The left temporal bone. Internal surface.



of the squamous and tympanic portions of the bone. It replaces the squamosal foramen already mentioned, and transmits the petrosquamous sinus (p. 849).

The *cerebral surface* of the squama (fig. 335) is concave; it presents depressions corresponding to the convolutions of the temporal lobe of the brain, and grooves for the branches of the middle meningeal vessels; its lower border is united to the anterior surface of the petrous portion but traces of a petrosquamosal suture are frequently seen in the adult bone.

The *superior border* is thin, bevelled at the expense of the cerebral surface, and overlaps the inferior border of the parietal bone, forming with it the squamosal suture. Posteriorly the superior border forms an angle with the mastoid portion of the bone. The *antero-inferior border*, thin above and thick below, articulates with the greater wing of the sphenoid bone; its upper part is bevelled at the expense of the cerebral surface, its lower at the expense of the temporal surface.

Although the **petromastoid part** of the temporal bone does not consist of two morphologically distinct elements (p. 320), it is convenient to describe its two constituent components independently of one another.

The **mastoid portion** forms the posterior part of the temporal bone. Its *outer surface* (fig. 334) is rough and gives attachment to the occipital belly of the occipitofrontalis, and the auricularis posterior muscle. It is frequently perforated near its posterior border by the *mastoid foramen*, which gives exit to a vein from the sigmoid sinus and entrance to a small branch of the occipital artery to the dura mater; the

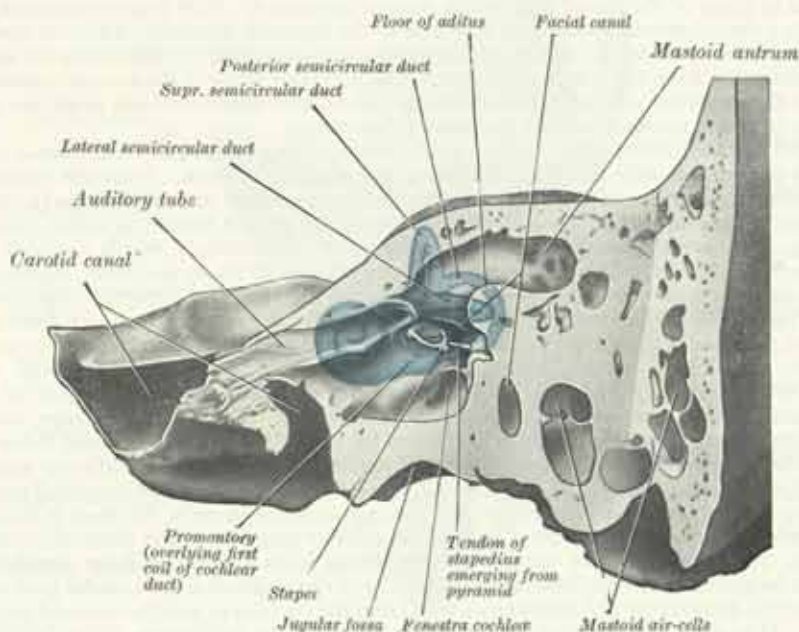
position and size of this foramen are very variable ; it may be situated in the occipital bone, or in the suture between the temporal and the occipital bones. The mastoid portion is continued below into a conical projection, named the **mastoid process** ; it is larger in the male than in the female. The lateral surface of this process gives insertion to the sternomastoid, splenius capitis, and longissimus capitis ; on its medial side there is a deep groove, termed the *mastoid notch*, for the attachment of the posterior belly of the digastric muscle ; medial to this notch the shallow *occipital groove* lodges the occipital artery.

On the *inner surface* of the mastoid portion (fig. 335) there is a deep, curved groove termed the *sigmoid sulcus*, which lodges the sigmoid sinus ; near its posterior border it receives the opening of the mastoid foramen. The sigmoid sulcus is separated from the innermost of the mastoid air-cells by a thin lamina of bone which may be partly deficient.

The *superior border* of the mastoid portion is thick and serrated for articulation with the mastoid angle of the parietal bone. The *posterior border*, also serrated,

FIG. 336.—A section through the left temporal bone in the long axis of the tympanic cavity. The lateral surface of the medial half of the bone is shown.

The positions of the duct of the cochlea and the semicircular ducts are shown in blue.



articulates with the inferior border of the occipital bone between the lateral angle and jugular process. The mastoid portion is fused with the descending process of the squamous part above ; below, it enters into the formation of the posterior wall of the tympanic cavity.

The *mastoid air-cells*, which are seen in sections of the mastoid process (fig. 336), and the *mastoid antrum*, with which they communicate, are described with the tympanic cavity in the section dealing with the Organ of Hearing.

The **petrous portion** of the temporal bone is wedged between the sphenoid and occipital bones at the base of the skull (figs. 307, 312). It is directed medially, forwards, and a little upwards ; it has a base, an apex, three surfaces, and three margins. The essential parts of the organs of hearing and equilibration are placed within it.

The *base* is continuous with the squamous and mastoid portions, and is partially separated from them by the mastoid antrum.

The *apex*, rough and uneven, is received into the angular interval between the posterior border of the greater wing of the sphenoid bone and the basilar part of the occipital bone ; it is pierced by the anterior orifice of the carotid canal and forms the posterolateral boundary of the foramen lacerum.

The *anterior surface* helps to form the floor of the middle cranial fossa and is continuous with the cerebral surface of the squamous part, although remains of the petrosquamosal suture are often distinct even at a late period of life.

The whole surface is marked by impressions for the gyri of the inferior surface of the temporal lobe of the brain. Immediately behind the apex a slight hollow lodges the trigeminal ganglion and it is termed the *trigeminal impression*. The bone anterior and slightly lateral to the impression forms the roof of the anterior part of the carotid canal; it is often deficient in this situation. An irregular ridge separates the trigeminal impression posteriorly from a second hollow, which forms part of the roof of the internal acoustic meatus and covers the cochlea. This concavity is limited behind by an elevation, termed the *arcuate eminence* (fig. 335), which is raised by the superior semicircular canal and, in its lateral part, roofs in the vestibule and the beginning of the facial canal. Between the squamous part on the lateral side, and the arcuate eminence and the hollows just described on the medial side, the surface is formed by the *tegmen tympani*. This thin plate of bone forms the roof of the mastoid antrum behind and extends forwards above the tympanic cavity (fig. 336) and the canal for the tensor tympani muscle. Its lateral margin meets the squamous part at the site of the petrosquamosal suture and turns downwards in front to form the lateral wall of the canal for the tensor tympani and the bony part of the auditory tube; the lower edge of this downturned portion has already been observed in the floor of the squamotympanic fissure (p. 288). Anteriorly the tegmen tympani presents a narrow groove, which runs backwards and laterally and enters the bone through an opening placed in front of the lateral part of the arcuate eminence. This hiatus transmits the greater petrosal nerve, which runs forwards to the foramen lacerum. A second groove may mark the bone on the lateral side of the one just described; it transmits the lesser petrosal nerve from the tympanic plexus. The posterior slope of the arcuate eminence covers the posterior and lateral semicircular canals, and lateral to it the posterior part of the tegmen tympani roofs in the mastoid antrum.

The *posterior surface* (fig. 335) forms the anterior part of the posterior cranial fossa and is continuous with the inner surface of the mastoid portion. Near the centre of this surface an orifice of varying size leads into the *internal acoustic meatus* (p. 297). Behind the opening of the meatus there is a small slit almost hidden by a thin plate of bone; it leads to a canal, named the *aqueduct of the vestibule*, which contains the saccus* and ductus endolymphaticus together with a small artery and vein. Above and between these two openings the *subarcuate fossa* (p. 298) forms an irregular depression.

The *inferior surface* (fig. 337), rough and irregular, forms part of the external surface of the base of the skull. Near the apex a quadrilateral rough surface serves partly for the attachment of the levator veli palatini muscle and the cartilaginous portion of the auditory tube, and partly for connexion with the basilar part of the occipital bone, some dense fibrous tissue intervening. Behind this a large, nearly circular aperture, leads into the *carotid canal* (p. 286). Behind this opening there is a deep depression, termed the *jugular fossa*, of variable depth and size in different skulls; it lodges the superior bulb of the internal jugular vein. In front of the medial part of the jugular fossa and directly below the internal acoustic meatus, the bone is marked by a triangular depression, which lodges the inferior ganglion of the glossopharyngeal nerve. At the apex of this notch a small opening leads into the *cochlear canaliculus*, which lodges the perilymphatic duct (aqueduct of the cochlea) and a tubular prolongation of the dura mater and transmits a vein from the cochlea to join the internal jugular vein. It is generally believed that through the duct the perilymph of the labyrinth is enabled to drain away into the subarachnoid space.† On the bony ridge dividing the carotid canal from the jugular fossa there is a small *canaliculus for the tympanic nerve*, which is derived from the glossopharyngeal nerve (p. 290). In the lateral part of the jugular fossa the bone is pierced by the *mastoid canaliculus* for the entrance of the auricular branch of the vagus nerve. Behind the jugular fossa the *jugular surface* forms a rough quadrilateral area covered with cartilage in the recent state and articulating with the jugular process of the occipital bone.

The *superior border*—the longest—is grooved for the superior petrosal sinus and gives attachment to the tentorium cerebelli, except at its medial extremity, where it is crossed by the roots of the trigeminal nerve. The *posterior border* is intermediate in length between the superior and the anterior. Its medial part is marked by a sulcus, which forms, with a corresponding sulcus on the occipital bone, the channel for the inferior petrosal sinus. Behind this there is the *jugular fossa*, which, with the jugular notch on the occipital bone, forms the jugular foramen; it presents a notch for the

* The terminal half or more of the saccus endolymphaticus protrudes through the narrow orifice and lies between the periosteum and the covering dura mater.

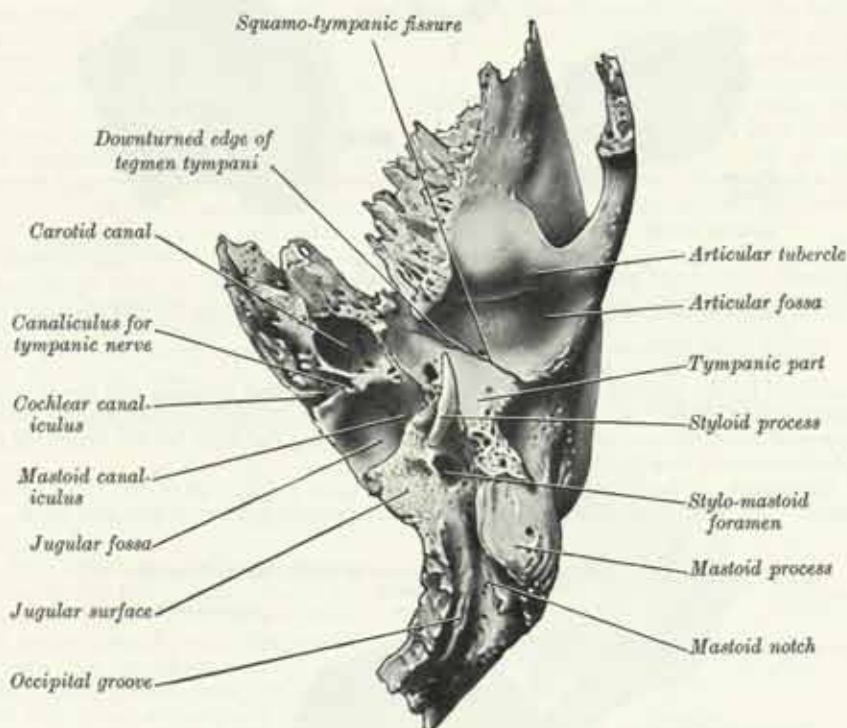
† M. Wharton Young, *Anat. Rec.* 112 and 115, 1952 and 1953, denies that the perilymph drains into the subarachnoid space and asserts that the aqueduct of the cochlea ends in a blind sac.

glossopharyngeal nerve, and either or both of the extremities of the notch may meet the occipital bone and divide the foramen into two, sometimes three, parts. The *anterior border* is divided into two parts—a lateral, joined to the squamous part at the *petrosquamosal suture*; a medial, free, for articulation with the greater wing of the sphenoid bone.

At the angle of junction of the petrous and squamous parts two canals are placed one above the other, and separated by a thin plate of bone. Both canals lead into the tympanic cavity; the upper transmits the tensor tympani; the lower forms the canal of the auditory tube.

The **tympanic part** of the temporal bone (fig. 337) is a curved plate lying below the squamous part and in front of the mastoid process. Internally, it is fused with the petrous portion, and appears in the angle between it and the squamous part, where it lies below and lateral to the orifice of the auditory tube. Behind, it fuses with the squamous part and the mastoid process, and forms the anterior boundary of the

FIG. 337.—The left temporal bone. Inferior surface.



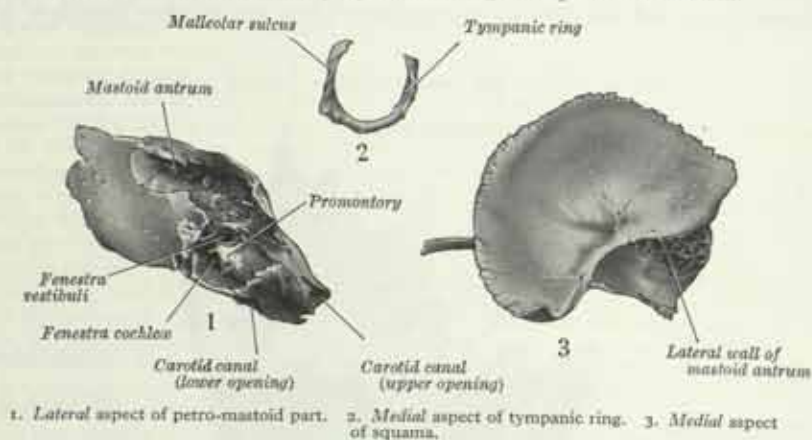
tympanomastoid fissure. Its *posterior surface* is concave and forms the anterior wall, the floor, and a part of the posterior wall of the bony external acoustic meatus; at the medial end of this surface there is a narrow furrow, termed the *tympanic sulcus*, for the attachment of the circumference of the tympanic membrane. Its *anterior surface*, quadrilateral and slightly concave, constitutes the posterior wall of the mandibular fossa and is sometimes in contact with a part of the parotid gland. Its *lateral border* is free and roughened; it forms a large part of the margin of the opening of the external acoustic meatus and gives attachment to the cartilaginous part of the meatus. The lateral part of the *upper border* is fused with the back of the postglenoid tubercle; its medial part forms the posterior boundary of the petrotympanic fissure. The *lower border* is sharp; its lateral part splits to enclose the root of the styloid process and is therefore named the *sheath of the styloid process*. The central portion of the tympanic part of the temporal bone is thin, and in a considerable percentage of skulls is perforated by a foramen. Between the styloid and mastoid processes the *stylomastoid foramen*, which is the lower end of the facial canal, transmits the facial nerve and the stylomastoid artery.

The *external acoustic meatus*, which is about 16 mm. long, is directed inwards and slightly forwards and downwards; its floor is convex upwards. On sagittal section the meatus is oval or elliptical in shape with the long axis directed downwards and slightly backwards. Its anterior wall, its floor and the lower part of its posterior wall

are formed by the tympanic part of the bone; its roof and the upper part of its posterior wall by the squamous part. Its inner end is closed in the recent state by the tympanic membrane; its outer end is bounded above by the posterior root of the zygomatic process, below which the small *suprameatal spine* is sometimes seen at the upper and posterior part of the orifice.

The **styloid process** of the temporal bone, slender, pointed, and averaging about 2.5 cm. in length, projects downwards and forwards, from the under surface of the bone. Its proximal part (tympanohyal) is surrounded by a bony sheath, derived from the tympanic plate and best marked on its anterolateral aspect, while its distal part (stylohyal) gives attachment to certain muscles and ligaments (p. 281). The process

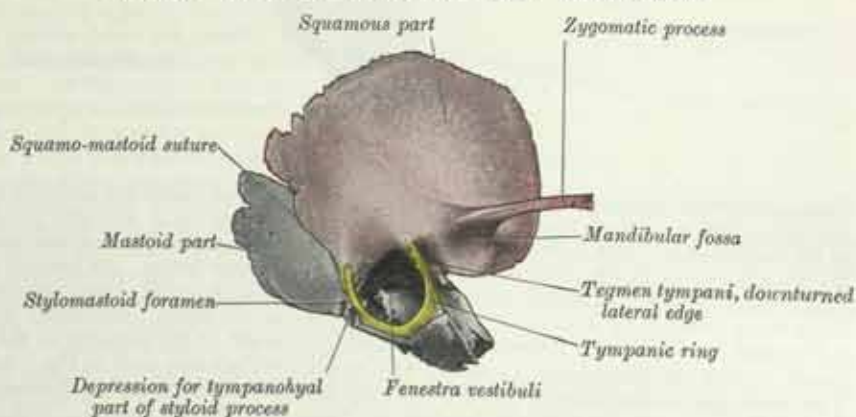
FIG. 338.—The three principal parts of the right temporal bone at birth.



is covered by the parotid gland, and the facial nerve crosses its base, and the external carotid artery its tip, as they lie within the gland. On its deep surface the process is separated from the commencement of the internal jugular vein by the origin of the stylopharyngeus muscle.

Structure.—The structure of the squamous part is like that of the other cranial bones: the mastoid portion is spongy, and the petrous portion dense and hard.

FIG. 339.—The right temporal bone at birth. Lateral aspect.



Note.—The petromastoid part has not been coloured; the tympanic part is coloured yellow and the squamous part is coloured crimson. The whole of the styloid process has been removed.

Ossification.—The temporal bone is ossified from eight centres (exclusive of those for the internal ear and the tympanic ossicles)—viz. one each for the squamous and the tympanic part, four for the petrous and mastoid parts, and two for the styloid process. Just before birth, the bone consists of three principal parts, viz.: the squamous, the petromastoid part, and the tympanic ring (fig. 338). The *squamous part* is ossified in membrane from a single centre, which appears in the region of the root of the

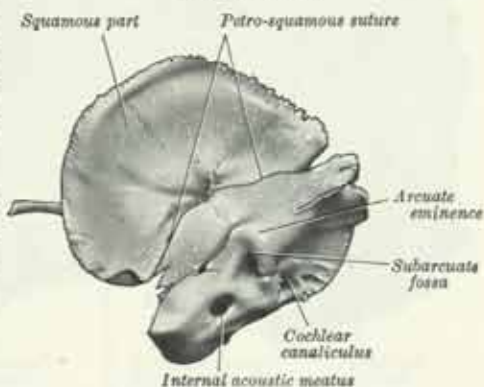
zygomatic process about the seventh or eighth week and soon extends in an upward direction. The *petromastoid* part is developed from four centres, which make their appearance in the cartilaginous ear-capsule (p. 151) about the fifth or sixth month of intrauterine life. One (pro-otic) appears in the neighbourhood of the arcuate eminence, spreads in front of and above the internal acoustic meatus and extends to the apex of the bone; it covers part of the cochlea, vestibule, superior semicircular duct, and medial wall of the tympanic cavity. A second (opisthotic) appears at the promontory on the medial wall of the tympanic cavity and surrounds the fenestra cochleae; it forms the floor of the tympanic cavity and vestibule, surrounds the carotid canal, invests the lateral and lower parts of the cochlea, and spreads below the internal acoustic meatus. A third (pterotice) forms the tegmen tympani; while the fourth (epiotic) appears near the posterior semicircular duct and extends to form the mastoid process (Vrolik). The *tympanic ring* is an incomplete circle, deficient above, the concavity of which is grooved by the tympanic sulcus, for the attachment of the circumference of the tympanic membrane. The *malleolar sulcus* runs obliquely downwards and forwards across the inner aspect of the anterior part of the ring (fig. 338). It lodges the anterior process of the malleus, the chorda tympani nerve and the anterior tympanic artery. The tympanic ring expands to form the tympanic part of the bone and is ossified in membrane from a single centre which appears about the third month. The *styloid process* is developed from the cranial end of the cartilage of the second visceral or hyoid arch (p. 110) by two centres: one for the proximal part of the process, termed the tympanohyal, appears before birth; the other, for the distal part of the process, termed the stylohyal, does not appear until after birth. The tympanic ring unites with the squamous part shortly before birth; the petromastoid fuses with the squamous part during the first year, and with the tympanohyal portion of the styloid process about the same time. The stylohyal does not unite with the rest of the bone until after puberty, and in some skulls never at all.

During the process of ossification, the tympanic cavity, the tympanic antrum and the posterior end of the auditory tube are all enclosed within the bone. Broadly speaking, the petrous part forms the roof, floor and medial wall of the cavity, while the squamous and tympanic parts, together with the membrana tympani, form the lateral wall. At birth, the tympanic cavity, the mastoid antrum and the tympanic membrane are all of approximately adult size and so, too, are the auditory ossicles, although the anterior process of the malleus does not join the rest of the bone until six months later.

After birth the chief changes in the temporal bone, apart from increase in size, are: (1) The tympanic ring grows laterally and backwards to form the tympanic part of the bone. This growth does not, however, take place at an equal rate all round the ring, but occurs most rapidly on its anterior and posterior portions, and these outgrowths meet and blend, and thus, for a time, there exists in the floor of the meatus a foramen, (often named the *foramen of Huschke*): this foramen is usually closed about the fifth year, but may persist throughout life. (2) the mandibular fossa is at first extremely shallow and looks more laterally than downwards; it becomes deeper and is ultimately directed downwards. The postero-inferior portion of the squamous part grows downwards behind the tympanic ring and forms the lateral bony wall of the mastoid antrum. (3) The mastoid portion is at first flat, and the stylo-mastoid foramen and rudimentary styloid process lie immediately behind the tympanic ring. With the development of the mastoid air cells the lateral part of the mastoid portion grows downwards and forwards to form the mastoid process, and the styloid process and stylomastoid foramen come to lie on the under surface of the bone. The descent of the stylomastoid foramen is necessarily accompanied by a corresponding increase in the length of the canal for the facial nerve. It is not until the latter part of the second year that the mastoid process forms a definite elevation on the surface of the skull. (4) The subarcuate fossa on the posterior surface of the petrous portion is gradually filled and almost obliterated.

Applied Anatomy.—The external acoustic meatus is relatively as long in the child as in the adult, but in the child the canal is fibro-cartilaginous, whereas in the adult the inner two-thirds of it are osseous. When it is necessary to open the tympanum for

FIG. 340.—The right temporal bone at birth.
Medial aspect.



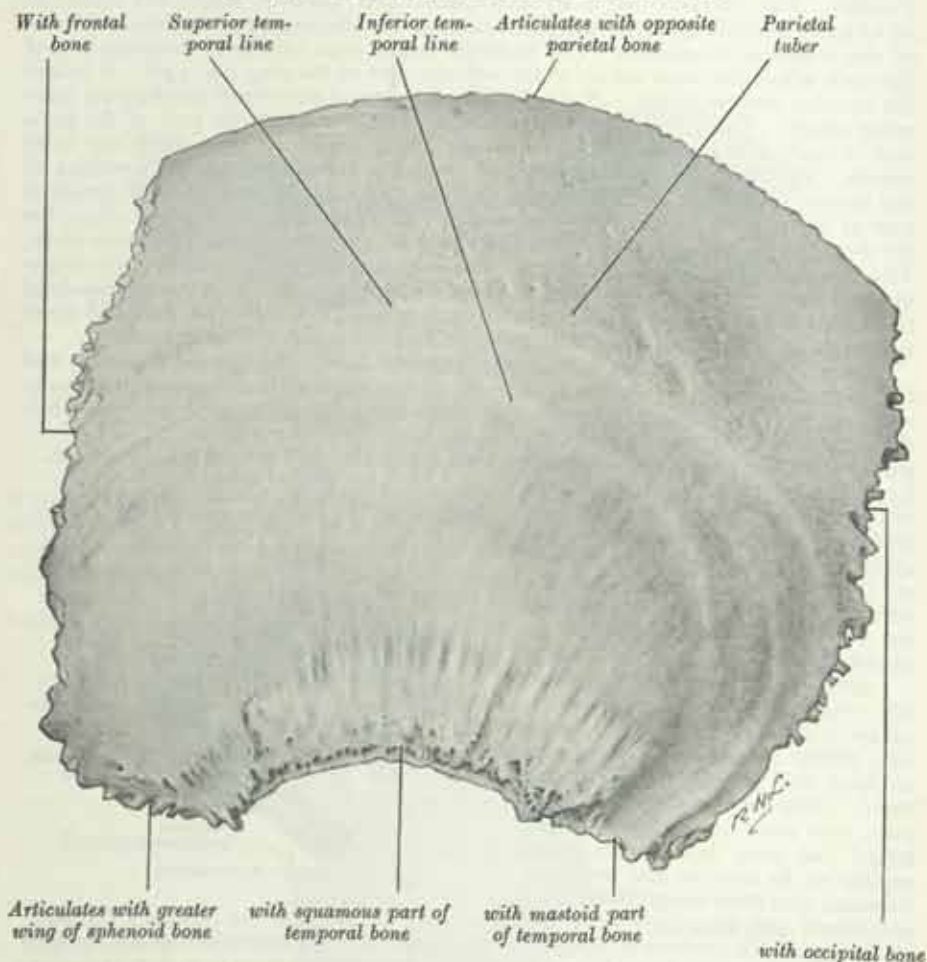
suppuration, it is approached through the mastoid antrum. *In the child only a thin scale of bone requires to be removed from the suprameatal triangle to open into the antrum.*

THE PARIETAL BONES

The **parietal bones** form the sides and the roof of the cranium. Each bone is irregularly quadrilateral in shape, and has two surfaces, four borders, and four angles.

The *external surface* (fig. 341) is convex, smooth, and marked near the centre by a slight elevation, termed the *parietal tuber*. Two curved lines, termed the *superior*

FIG. 341.—The left parietal bone. External surface.



and *inferior temporal lines*, cross the middle of the bone, forming an arch which is convex upwards and backwards; the former gives attachment to the temporal fascia; the latter marks the upper limit of the origin of the temporal muscle. The part of the bone above these lines is covered, in the recent condition, with the *galea aponeurotica*; that below the lines forms a part of the temporal fossa. At the posterior part, and close to the upper or sagittal border, the *parietal foramen* transmits a vein from the superior sagittal sinus and, sometimes, a small branch of the occipital artery; the foramen is not constantly present.

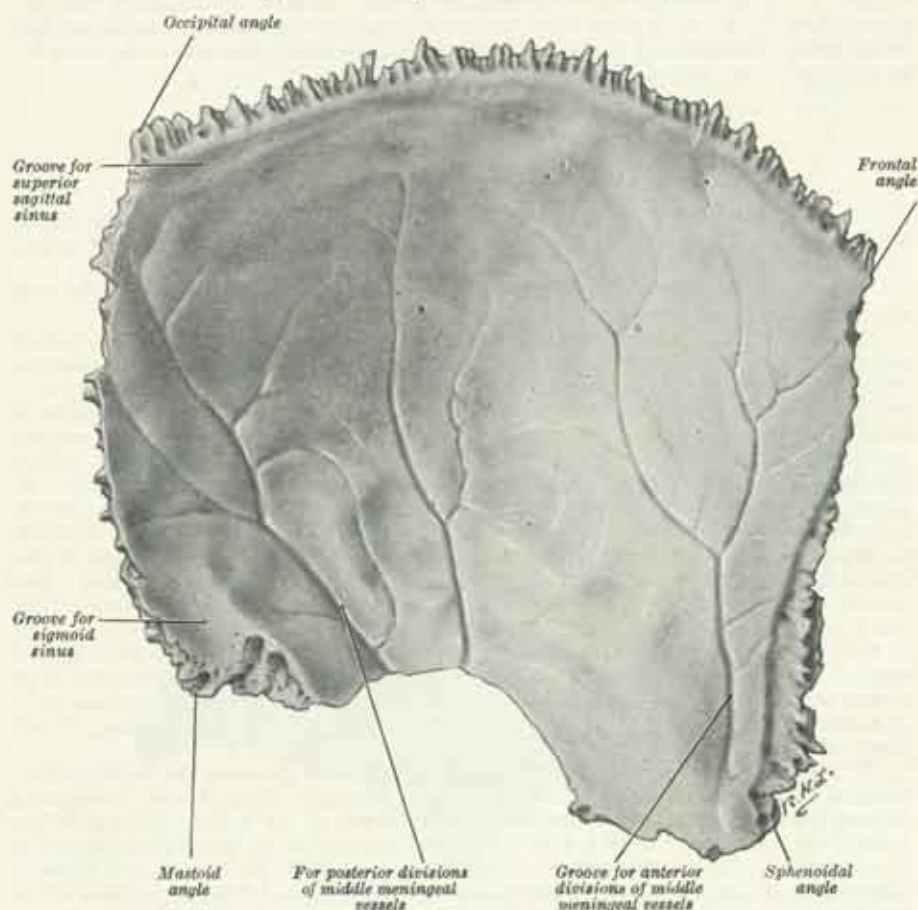
The *internal surface* (fig. 342) is concave; it presents *impressions for the cerebral gyri*, and numerous furrows for the ramifications of the middle meningeal vessels; these furrows run upwards and backwards from the sphenoidal (anterior inferior) angle, and from the middle and posterior part of the inferior border. Along the sagittal

* F. Wood Jones, *J. Anat. and Physiol.*, 46, 1911, and B. Coen, *J. Anat. and Physiol.*, 48, 1913.

border there is a shallow groove, which, with that on the opposite parietal bone, forms the *sagittal sulcus* for the superior sagittal sinus; to the edges of this sulcus the *falx cerebri* is attached. A number of *granular foveolæ* (*pits*), which lodge arachnoid granulations, mark the bone in the neighbourhood of the sagittal sulcus; they are best marked in the skulls of old persons.

The *sagittal border*—the longest and thickest—is dentated; it articulates with the corresponding border of the opposite parietal bone to form the sagittal suture. The *squamosal border* is divided into three parts: of these, the anterior is short, thin and truncated; it is bevelled at the expense of the external surface, and is overlapped by

FIG. 342.—The left parietal bone. Internal aspect.



the tip of the greater wing of the sphenoid; the middle portion is arched, bevelled at the expense of the external surface, and overlapped by the squamous part of the temporal bone; the posterior part is short, thick and serrated, and articulates with the mastoid portion of the temporal bone. The *frontal border* is deeply serrated, and bevelled at the expense of the external surface above and of the internal below; it articulates with the frontal bone, forming one-half of the coronal suture. The *occipital border*, which is deeply dentated, articulates with the occipital bone, forming one-half of the lamboid suture.

The *frontal angle* is almost a right angle, and corresponds with the *bregma* or point of meeting of the sagittal and coronal sutures. The *sphenoidal angle* is received into the interval between the frontal bone and the greater wing of the sphenoid. Its internal surface is marked by a deep groove—sometimes a canal—for the anterior divisions of the middle meningeal vessels. In some skulls the frontal bone articulates with the squama of the temporal bone, and the parietal bone then fails to reach the greater wing of the sphenoid. The region where these four bones approach closely to one another is termed the *pterion* (p. 277). The *occipital angle* is rounded

and corresponds with the *lambda* or point of meeting of the sagittal and lambdoid sutures. The *mastoid angle* is blunt and articulates with the occipital bone and with the mastoid portion of the temporal bone, the meeting point of the three bones being named the *asterion*. On the internal surface of this angle there is a broad, shallow groove, which lodges the end of the transverse sinus and the commencement of the sigmoid sinus.

At birth there are unossified or membranous intervals in the skull at the angles of the parietal bones; they are named fontanelles and are described on pp. 352, 353.

Ossification.—The parietal bone is ossified in membrane from two centres, which appear one above the other at the parietal tuber about the seventh week of intra-uterine life. These centres unite early, and ossification gradually extends in a radial manner towards the margins of the bone; the angles are consequently the parts last formed, and it is here that the fontanelles are found. At birth the temporal lines are situated low down; they reach their permanent position only after the eruption of the molar teeth. Occasionally the parietal bone is divided into upper and lower parts by an anteroposterior suture.

THE FRONTAL BONE

The **frontal bone** resembles a cockle-shell in shape, and forms the region of the forehead; on each side it has a horizontal *orbital part*, which enters into the formation of the roof of the orbital cavity.

The frontal bone has six surfaces, viz.—external, right and left temporal, right and left orbital, and internal.

The *external surface* (fig. 343) presents a rounded elevation, termed the *frontal tuber* on each side of the median plane, about 3 cm. above the supraorbital margin. These eminences vary in size in different individuals, are occasionally asymmetrical, and are especially prominent in young skulls. Below the frontal tubera, and separated from them by a shallow groove, there are two curved *superciliary arches*, the medial parts of which are prominent and joined to each other by a smooth elevation named the *glabella*. These arches are larger in the male than in the female, and their degree of prominence depends to some extent on the size of the frontal sinuses; prominent superciliary arches are, however, occasionally associated with small sinuses. Beneath the superciliary arches the curved *supra-orbital margins* form the upper borders of the orbital openings. The lateral two-thirds of each supra-orbital margin are sharp; the medial one-third is rounded. At the junction of these two parts the *supra-orbital notch*, or *foramen*, is situated; it transmits the supra-orbital vessels and nerve. Medial to this notch, the small *frontal notch* or *foramen* is present in about 50 per cent. of skulls. The supra-orbital margin ends laterally in the *zygomatic process*, which is strong and prominent and articulates with the zygomatic bone. From this process a line curves upwards and backwards and soon divides into the *superior* and *inferior temporal lines*.

The portion of the bone which projects downwards between the supra-orbital margins is named the *nasal part*. It presents a rough, serrated area, sometimes termed the *nasal notch*, which articulates on each side of the median plane with the nasal bone, and lateral to this with the frontal process of the maxilla and with the lacrimal bone. From the centre of the notch posteriorly the *nasal part* projects downwards and forwards behind the nasal bones (fig. 315) and frontal processes of the maxillæ, and supports the bridge of the nose. The nasal part ends below in a sharp *nasal spine*, and on each side of this there is a small grooved surface which forms a part of the roof of the corresponding nasal cavity. The nasal spine forms a very small part of the septum of the nose; in front it articulates with the crest of the nasal bones, behind with the perpendicular plate of the ethmoid bone (fig. 315).

The *temporal surface*, below and behind the temporal lines, forms the anterior part of the temporal fossa and gives origin to a part of the temporal muscle (fig. 313).

The *internal surface* (fig. 344) of the frontal bone is concave. In the upper part of the median plane it is marked by a vertical groove, termed the *sagittal sulcus*, the edges of which unite below to form the *frontal crest*; the sulcus lodges the anterior part of the superior sagittal sinus, while to its margins and to the frontal crest the anterior part of the falx cerebri is attached. The crest ends below in a small notch, which is converted into the *foramen cæcum* (p. 292) by articulation with the ethmoid bone. On each side of the median plane the surface is marked by *impressions for the cerebral gyri*, and minute furrows for meningeal vessels. Several small, irregular fossæ, termed *granular foveolæ*, may be seen on each side of the sagittal sulcus, for the reception of arachnoid granulations.

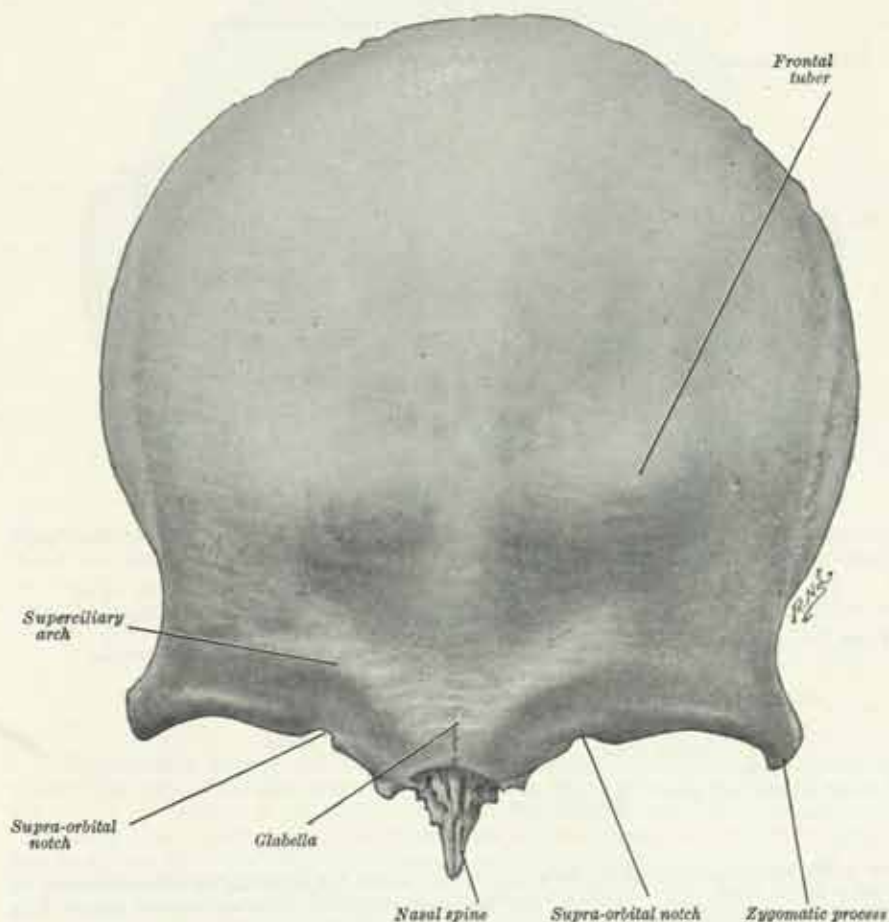
The *parietal margin* is thick, strongly serrated, bevelled at the expense of the internal surface above, where it rests upon the parietal bones, and at the expense of

the temporal surface on each side, where it receives the lateral pressure of the parietal bones; it is continued below into a triangular, rough surface, for articulation with the greater wing of the sphenoid bone.

The **orbital parts** of the frontal bone consist of two thin triangular lamellæ, which form the roofs of the orbits, and are separated from each other by a wide gap named the *ethmoidal notch*.

The *orbital surface* (fig. 344) of each orbital plate is smooth and concave, and presents, in its anterolateral part, a shallow depression which lodges the lacrimal gland and consequently is termed the *fossa for the lacrimal gland*; below and behind the medial end of the supra-orbital margin, about midway between the supra-orbital

FIG. 343.—The frontal bone. Frontal surface.



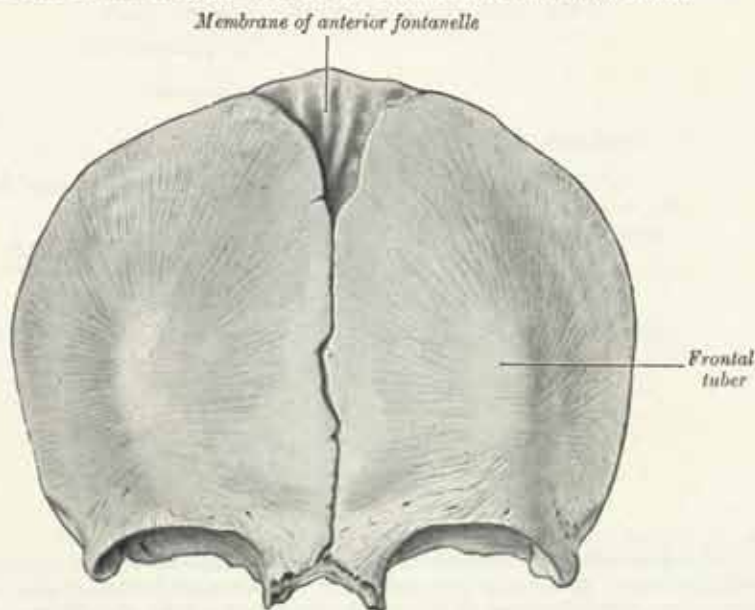
notch and the fronto-lacrimal suture, there is a small depression, sometimes a tiny spine, for the attachment of the fibrocartilaginous pulley of the superior oblique muscle and termed the *trochlear fovea* or *spine*, as the case may be. The *internal surface* is convex, and marked by impressions for the gyri on the inferior surface of the frontal lobe of the brain, and by faint grooves for the meningeal branches of the ethmoidal vessels.

The *ethmoidal notch* (fig. 343) separates the two orbital parts; it is quadrilateral in outline and is occupied, in the articulated skull, by the cribriform plate of the ethmoid bone. On the under surfaces of the lateral margins of the notch portions of several air-sinuses are present: they complete the ethmoidal sinuses when the ethmoid bone is in position. Two transverse grooves cross each margin of the notch; they are converted into the *anterior* and *posterior ethmoidal canals* by the ethmoid bone, and open on the medial wall of the orbit, from which they transmit the anterior and posterior ethmoidal nerves and vessels.

The openings of the *frontal sinuses* (fig. 344) are situated in front of the ethmoidal notch, and lateral to the nasal spine. These sinuses are two irregular cavities, which

region of each superciliary arch. From each of these centres ossification extends upwards to form the corresponding half of the bone, backwards to form the orbital part and downwards to form the nasal part of the bone. No secondary centres of ossification* occur in connexion with any part of the bone, with the possible exception of

FIG. 345.—The frontal bone at birth. Viewed from in front. Note that at this stage the bone consists of right and left halves connected by the frontal suture.



the nasal spine, for which two secondary centres have been described as appearing about the tenth year. At birth the bone consists of two halves separated by the frontal or *metopic suture*, but union begins in the second year, and the frontal suture is usually obliterated by the eighth year. In a few cases the two halves of the bone fail to unite and the metopic suture persists.

THE ETHMOID BONE

The **ethmoid bone** is cuboidal in shape, and exceedingly light; it is situated at the anterior part of the base of the cranium, and assists in forming the medial walls of the orbits, the septum of the nose, and the roof and lateral walls of the nasal cavity. It consists of four parts: a horizontal, perforated plate named the cribriform plate, a perpendicular plate and two lateral masses, named labyrinths.

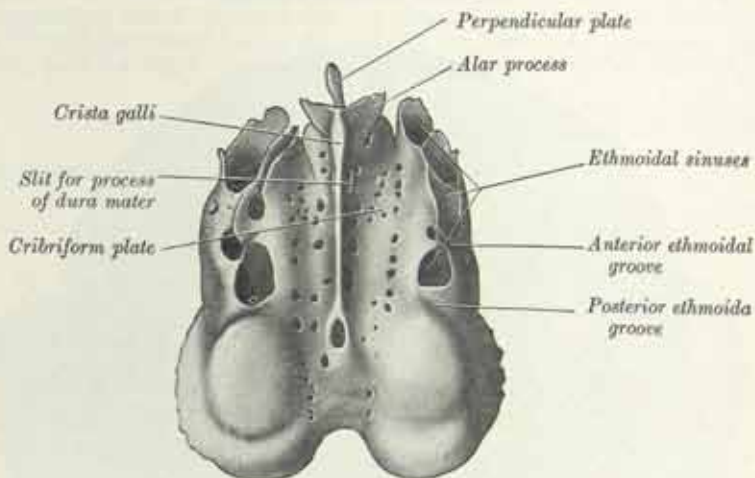
The **cribriform plate** (fig. 346) occupies the ethmoidal notch of the frontal bone, and forms a part of the roof of the nasal cavity. A thick, smooth, triangular process, called the *crista galli* from its resemblance to a cock's comb, projects upwards from this lamina in the median plane. Its posterior border, long, thin, and curved, gives attachment to the falx cerebri. Its anterior border, short and thick, articulates with the frontal bone by two small projecting *alæ* which complete the foramen cæcum (p. 292). Its sides are smooth, and sometimes bulging owing to the presence of a small air-sinus in the interior. On each side of the *crista galli* the cribriform plate is narrow and depressed; it supports the gyrus rectus and presents numerous foramina for the passage of the olfactory nerves. At the front part of the cribriform plate, on each side of the *crista galli*, there is a small slit-like fissure, which is occupied by a process of dura mater. The foramen which transmits the anterior ethmoidal nerve to the nasal cavity is placed lateral to the anterior end of the fissure, and to it a groove runs forwards from the orifice of the anterior ethmoidal canal.

The **perpendicular plate** of the ethmoid (figs. 347, 348), is thin, flat and quadrilateral in form. It descends from the under surface of the cribriform plate and forms the upper part of the nasal septum; it is generally deflected a little to one or other side. The *anterior border* articulates with the nasal spine of the frontal bone and the

* V. T. Inman and J. B. de C. M. Saunders, *J. Anat.*, 71, 1937.

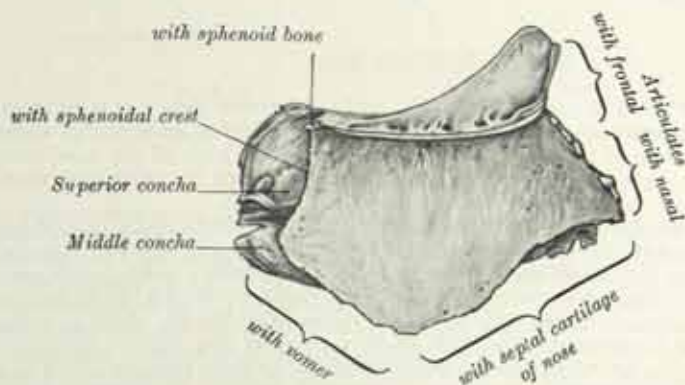
crest of the nasal bones. The *posterior border* articulates with the sphenoidal crest above and with the vomer below. The *superior border* is attached to the cribriform plate. The *inferior border* is thick, and serves for the attachment of the septal cartilage of the nose. The surfaces of the lamina are smooth, except above, where numerous grooves and canals are seen; these lead to the medial foramina in the cribriform plate and lodge filaments of the olfactory nerves.

FIG. 346.—The ethmoid bone. Superior aspect.



Each **labyrinth** of the ethmoid bone consists of a number of thin-walled *ethmoidal cellules*, arranged in three groups—*anterior*, *middle*, and *posterior*—and interposed between two vertical plates of bone; the lateral or *orbital plate* forms part of the medial wall of the orbit, the medial plate, part of the lateral wall of the nasal cavity.* In the disarticulated bone many of these ethmoidal cellules are opened, but in the articulated skull they are everywhere closed, except at their apertures of communica-

FIG. 347.—The perpendicular plate of the ethmoid bone. Right lateral aspect. Shown after removal of the right labyrinth.



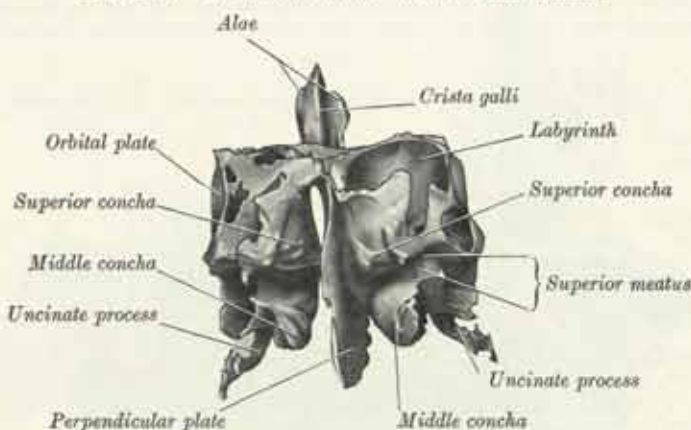
tion with the nasal cavity. The *upper surface* of the labyrinth (fig. 346) presents a number of cellules, the walls of which are completed, in the articulated skull, by the edges of the ethmoidal notch of the frontal bone (fig. 344). This surface is crossed by two grooves which are converted into the *anterior* and *posterior ethmoidal canals* by articulation with the frontal bone. On the *posterior surface* of each labyrinth (fig. 348) large cellules are visible, and their walls are completed by the sphenoidal concha and the orbital process of the palatine bone. The *lateral surface* (fig. 349) consists of

* Some anatomists divide the ethmoidal sinuses into two groups, an *anterior*, comprising those which open into the middle meatus, and a *posterior*, those which open into the superior meatus of the nose.

a thin, smooth, oblong plate, named the *orbital plate*, which covers the middle and posterior ethmoidal sinuses and forms a large part of the medial wall of the orbit; it articulates above with the orbital part of the frontal bone, below with the maxilla and the orbital process of the palatine bone, in front with the lacrimal bone, and behind with the sphenoid bone (fig. 301).

A few cellules lie in front of the orbital plate and their walls are completed by the lacrimal bone and the frontal process of the maxilla. A thin, curved bar of bone,

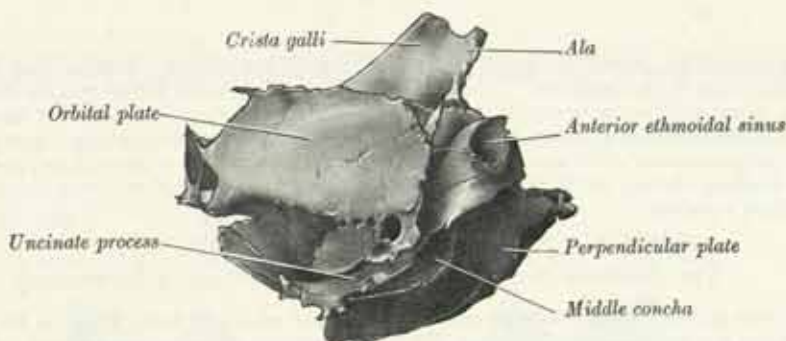
FIG. 348.—The ethmoid bone. Viewed from behind.



termed the *uncinate process*, which is subject to considerable variation in size, projects downwards and backwards from this part of the labyrinth; it can be seen in the medial wall of the maxillary sinus (fig. 301) as it crosses the anterior part of the hiatus maxillaris to reach the ethmoidal process of the inferior nasal concha, with which it articulates. The upper edge of this process is free and forms the medial boundary of the hiatus semilunaris in the middle meatus of the nose.

The *medial surface* of the labyrinth (fig. 350) forms part of the lateral wall of the corresponding half of the nasal cavity; it consists of a thin lamella, which descends

FIG. 349.—The ethmoid bone. Viewed from the right side.



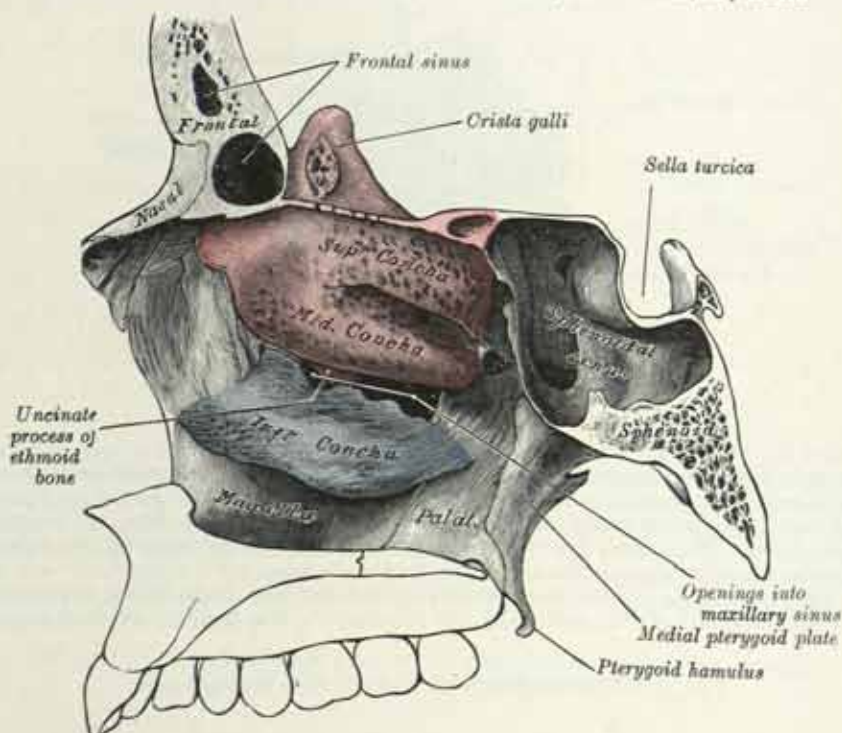
from the under surface of the cribriform plate and ends in a free, convoluted portion, named the *middle nasal concha*. The upper part of the medial surface is marked by numerous grooves, directed nearly vertically downwards; they lodge branches of the olfactory nerves. The posterior part of the medial surface is subdivided by a narrow, oblique fissure, termed the *superior meatus* of the nose, which is bounded above by a thin, curved plate, named the *superior nasal concha*; the posterior ethmoidal cellules open into this meatus. Below and in front of the superior meatus the convex surface of the middle nasal concha extends along the whole length of the medial surface of the labyrinth. Its lower margin is free and thick, while its lateral surface is concave and assists in forming the *middle meatus* of the nose. The middle ethmoid cellules produce a rounded swelling, named the *bullae ethmoidalis*, on the lateral wall of the middle meatus (fig. 351); on the bulla, or immediately above it, these cellules open into the

meatus. A curved passage, named the *infundibulum*, extends upwards and forwards from the middle meatus; it communicates with the anterior ethmoidal sinuses, and in rather more than 50 per cent. of skulls is continued upwards as the frontonasal duct into the frontal sinus.

Ossification.—The ethmoid bone is ossified in the cartilaginous nasal capsule from three centres; one for the perpendicular plate, and one for each labyrinth.

The centre for each labyrinth appears in the region of the orbital plate between the fourth and fifth months of intrauterine life, and extends into the conchæ. At birth, the

FIG. 350.—The lateral wall of the right half of the nasal cavity, showing the ethmoid bone (coloured red) and the inferior nasal concha (coloured blue) in position.



two labyrinths, which are small and ill-developed, are partially ossified, but the rest of the bone is cartilaginous. During the first year after birth, the perpendicular plate and crista galli begin to ossify from a single centre, and they fuse with the labyrinths about the beginning of the second year. The cribriform plate is ossified partly from the perpendicular plate and partly from the labyrinths. The ethmoidal cellules begin to develop during intrauterine life, and in the new-born infant have the form of narrow pouches.

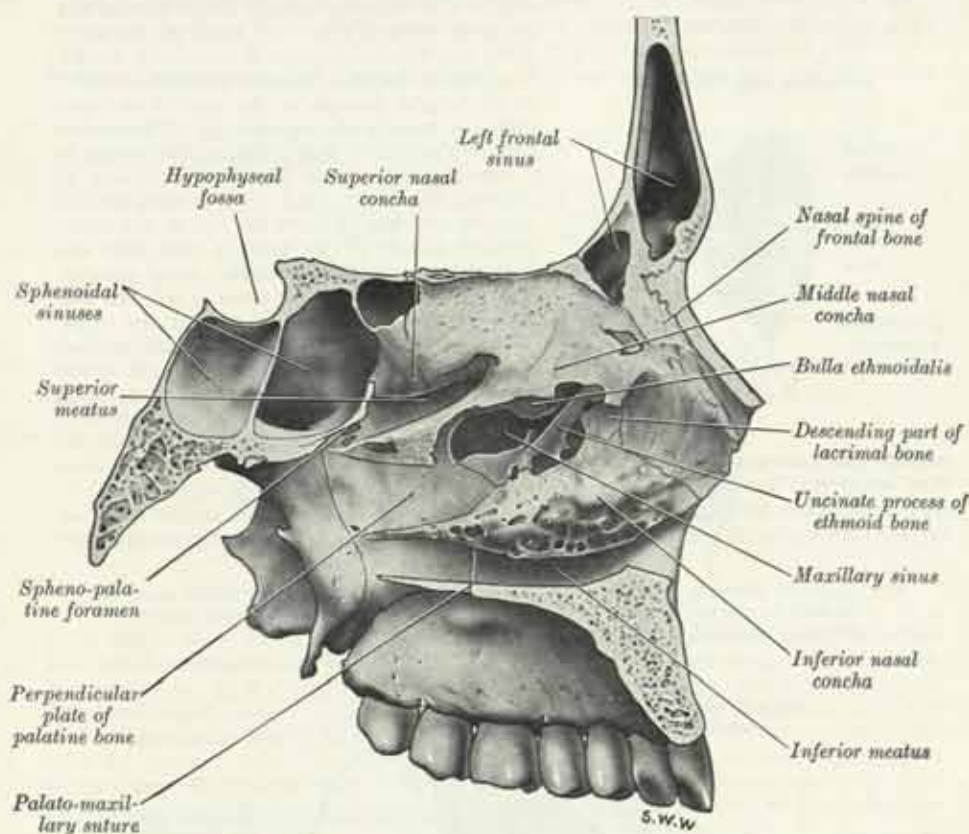
THE INFERIOR NASAL CONCHÆ (CONCHÆ NASALES INFERIORES)

The **inferior nasal conchæ** are curved laminæ which lie horizontally in the lateral walls of the nasal cavity (fig. 350). Each bone has two surfaces, two borders, and two ends.

The **medial surface** (fig. 352 A) is convex, perforated by numerous apertures, and traversed by longitudinal grooves for the lodgement of vessels. The **lateral surface** is concave (fig. 352 B), and forms part of the inferior meatus of the nasal cavity. The **superior border** is thin and irregular, and may be divided into three portions: of these, the anterior articulates with the conchal crest of the maxilla, and the posterior with the conchal crest of the palatine bone. The middle portion presents three processes, which vary in size and form. Of these, the **lacrimal process** is small and pointed and is situated at the junction of the anterior one-fourth with the posterior three-fourths of the bone: it articulates, by its apex, with a descending process from the lacrimal bone (fig. 353) and, by its margins, with the edges of the nasolacrimal groove on the medial surface of the body of the maxilla; it thus assists in forming the canal for the nasolacrimal duct. Behind this process a thin plate, named the **ethmoidal process**, ascends

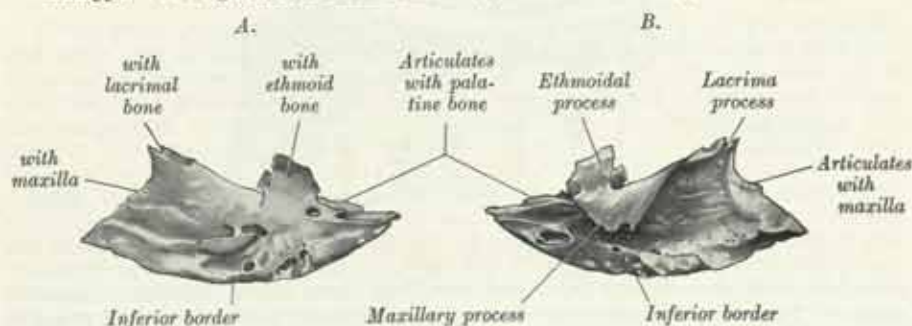
to join the uncinate process of the ethmoid (fig. 351). From the middle part of the superior border a thin lamella, termed the *maxillary process*, curves downwards and

FIG. 351.—The lateral wall of the left nasal cavity, with an irregularly shaped portion removed from the lower part of the middle concha.



laterally; it articulates with the maxilla and the maxillary process of the palatine bone, forming a part of the medial wall of the maxillary sinus (fig. 364). The *inferior border*

FIG. 352.—The right inferior nasal concha. (A) Medial surface. (B) Lateral surface.



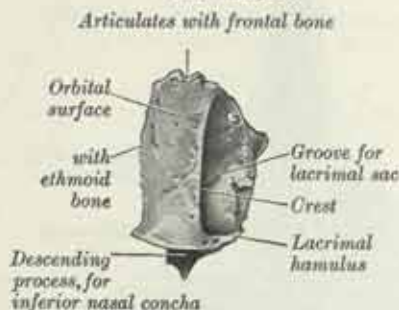
is free, thick, and spongy in structure, more especially in the middle of the bone. Both ends are more or less pointed, the posterior being the more tapered.

Ossification.—The inferior nasal concha is ossified from one centre; this appears about the fifth month of intrauterine life in the incurved lower border of the lateral wall of the cartilaginous nasal capsule. It loses continuity with the nasal capsule during ossification.

THE LACRIMAL BONES

The **lacrimal bones**, which are the smallest and most fragile of the cranial bones, are situated at the front parts of the medial walls of the orbits (fig. 300). Each lacrimal bone has two surfaces and four borders.

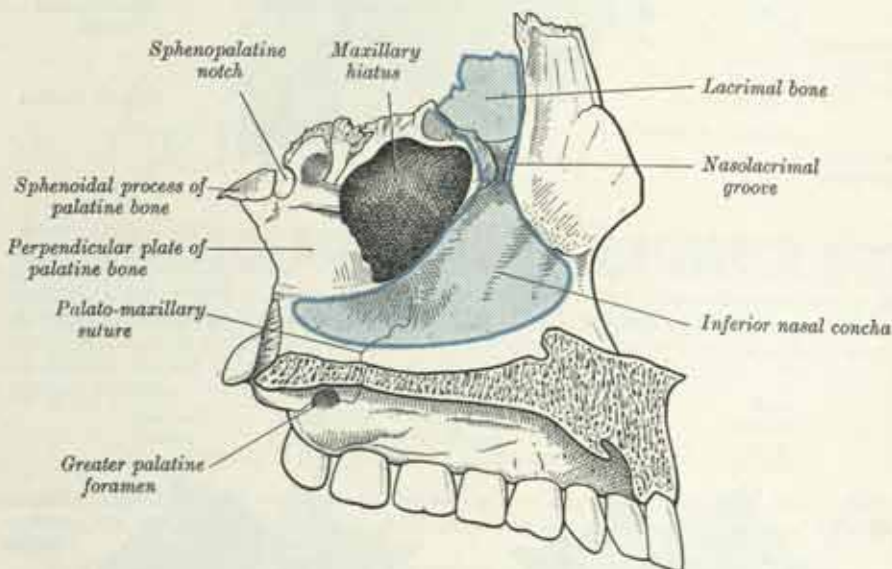
FIG. 353.—The right lacrimal bone. Lateral aspect.



The *lateral or orbital surface* (fig. 353) is divided by a vertical ridge, termed the *posterior lacrimal crest*. In front of this crest there is a vertical groove, the anterior border of which articulates with the posterior border of the frontal process of the maxilla to complete the *fossa for the lacrimal sac*. The medial wall of the groove is prolonged downwards as a descending process (fig. 354) to assist in forming the bony canal for the nasolacrimal duct by articulating with the lips of the nasolacrimal groove of the maxilla, and with the lacrimal process of the inferior nasal concha. The portion behind the crest is smooth and forms a part of the medial wall of the orbit. The crest, with a part of the orbital surface immediately posterior to it, gives origin to the lacrimal part of the orbicularis oculi muscle. The crest ends below in a small hook, termed the *lacrimal hamulus*, which articulates with the

maxilla and completes the upper orifice of the bony canal for the nasolacrimal duct (fig. 300); the lacrimal hamulus sometimes exists as a separate piece, and is then called the *lesser lacrimal bone*. The lower and anterior part of the *medial or nasal surface* forms part of the middle meatus of the nose; its upper and posterior part

FIG. 354.—A drawing to show how the medial wall of the nasolacrimal canal is formed by the articulation of the descending process of the lacrimal bone with the lacrimal process of the inferior nasal concha.



articulates with the ethmoid bone and completes some of the anterior ethmoidal cellules. The *anterior border* of the lacrimal bone articulates with the frontal process of the maxilla; the *posterior border* with the orbital plate of the ethmoid; the *superior border* with the frontal bone. The *inferior border* articulates with the orbital surface of the maxilla (fig. 300).

Ossification.—The lacrimal bone is ossified from one centre, which appears about the twelfth week of intrauterine life in the membrane covering the cartilaginous nasal capsule.

THE NASAL BONES

The **nasal bones** are two small oblong bones, varying in size and form in different individuals; they are placed side by side between the frontal processes of the maxillæ, and form, by their junction, 'the bridge' of the nose (figs. 297, 351).

Each nasal bone has two surfaces and four borders. The *external surface* (fig. 355), is concavo-convex from above downwards, and convex from side to side; it is covered by the procerus and compressor naris, and is perforated near its centre by a foramen for the transmission of a small vein. The *internal surface* (fig. 356) is concave

FIG. 355.—The left nasal bone.
External surface.

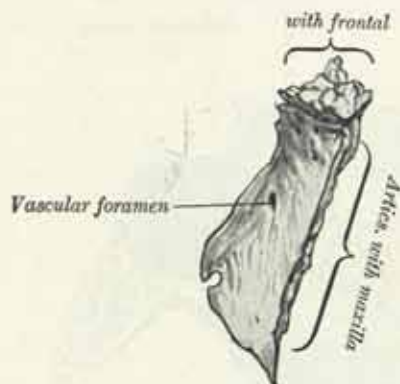
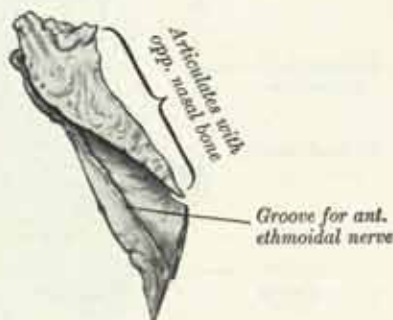


FIG. 356.—The left nasal bone.
Internal surface.



from side to side, and is traversed from above downwards by a groove which lodges the anterior ethmoidal nerve. The *superior border*, thick and serrated, articulates with the nasal part of the frontal bone. The *inferior border*, thin and notched, gives attachment to the lateral cartilage of the nose. The *lateral border* articulates with the frontal process of the maxilla. The *medial border*, thicker above than below, articulates with the opposite nasal bone and is prolonged behind into a vertical crest, which forms a small part of the septum of the nose, and articulates from above downwards, with the nasal spine of the frontal, the perpendicular plate of the ethmoid, and the cartilage of the septum of the nose.

Ossification.—The nasal bone is ossified from one centre, which appears at the beginning of the third month of intrauterine life in the membrane overlying the anterior part of the cartilaginous nasal capsule.

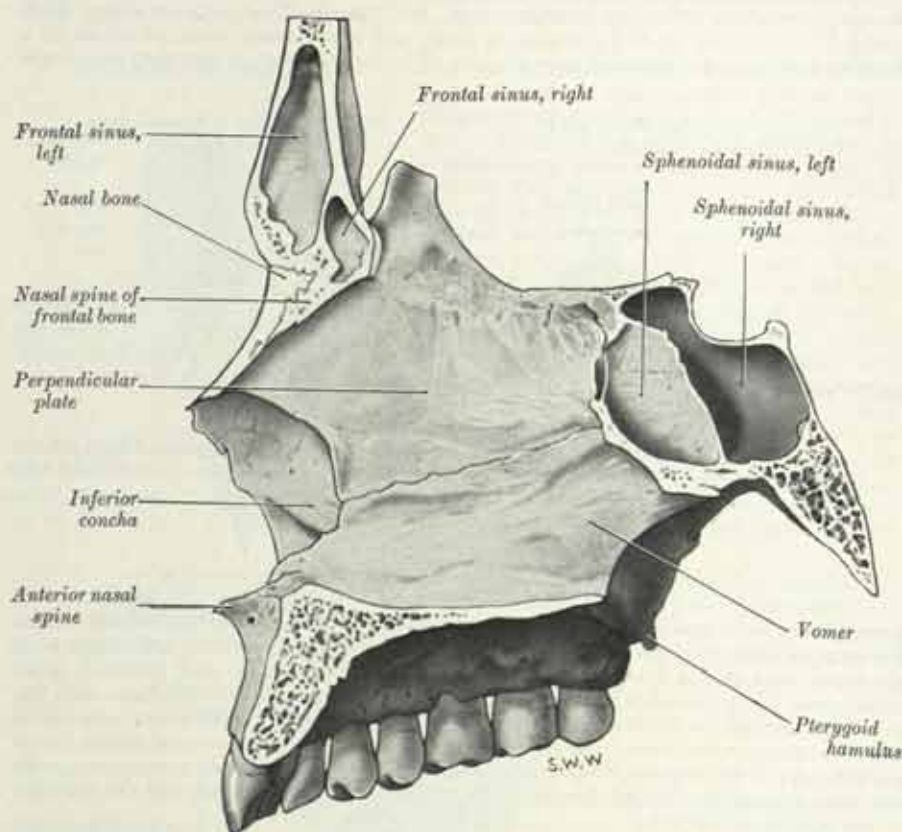
THE VOMER

The **vomer** is a thin, flat bone, almost quadrilateral in shape; it forms the hinder and lower part of the septum of the nose (fig. 357) and has two surfaces and four borders. Each *surface* (fig. 358) is marked by small furrows for blood-vessels, and is traversed by a groove which runs obliquely downwards and forwards, and lodges the nasopalatine nerve and the accompanying vessels. The *superior border* is the thickest, and presents a deep furrow, bounded on each side by a projecting *ala*: the furrow receives the rostrum of the sphenoid; the *alæ* articulate with the sphenoidal conchæ, the sphenoidal processes of the palatine bones and the vaginal processes of the medial pterygoid plates. When the edge of the *ala* occupies the interval between the body of the sphenoid and the vaginal process, its lower surface takes part in the formation of the vomerovaginal canal (p. 287). The *inferior border* articulates with the nasal crest formed by the maxillæ and palatine bones. The *anterior border* is the longest; its upper half articulates with the perpendicular plate of the ethmoid, its lower is cleft for the reception of the inferior margin of the cartilage of the septum of the nose. The *posterior border* is free, concave, and separates the posterior nasal apertures; it is thick and bifid above, thin below. The anterior end of the vomer articulates with the posterior margin of the incisive crest of the maxillæ and projects downwards between the incisive canals.

Ossification.—At an early period the septum of the nose consists of a plate of cartilage. The superior part of this cartilage is ossified to form the perpendicular plate of the ethmoid; its antero-inferior portion persists as the septal cartilage, whilst the

vomer is ossified in the membrane covering its postero-inferior part. About the eighth week of intrauterine life two centres of ossification, one on each side of the median plane, appear in this part of the membrane. About the third month these

FIG. 357.—The medial wall of the left half of the nasal cavity, showing the vomer *in situ*.



centres unite below the cartilage, and thus a deep groove is formed (fig. 359) in which the cartilage of the septum of the nose is lodged. As growth proceeds the union of the bony lamellæ extends upwards and forwards, and at the same time the intervening plate

FIG. 358.—The vomer. Left lateral aspect.

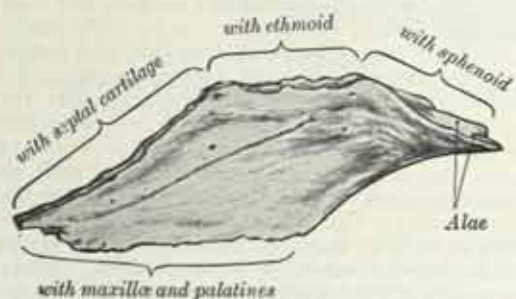


FIG. 359.—The vomer of a child at birth.

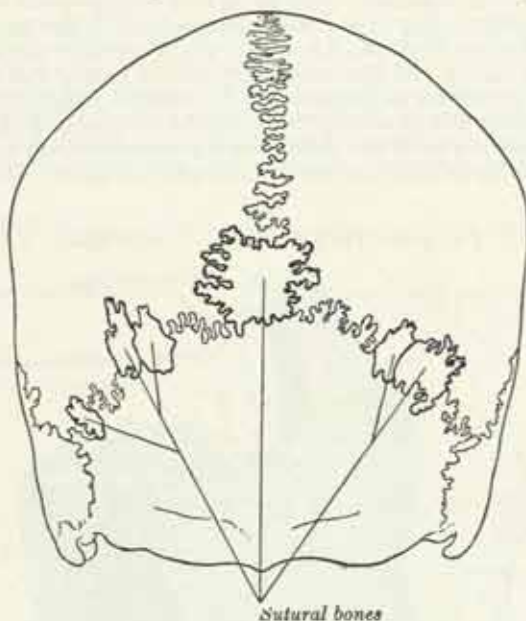


of cartilage undergoes absorption. By the age of puberty the lamellæ are almost completely united, but evidence of the bilaminar origin of the bone is seen in the everted alæ of its upper border and the groove on its anterior margin (fig. 358).

THE SUTURAL BONES (OSSA SUTURARUM)

In addition to the usual centres of ossification of the cranial bones, others may occur in the course of the sutures, giving rise to irregular, isolated, *sutural bones* (fig. 360). They occur most frequently in the course of the lambdoid suture, but are

FIG. 360.—A sketch showing sutural bones in the lambdoid and sagittal sutures.



occasionally seen at the fontanelles, especially the posterior. One—the *pterion ossicle*—sometimes exists between the sphenoidal angle of the parietal bone and the greater wing of the sphenoid bone. These bones vary much in size, but have a tendency to be more or less symmetrical on the two sides of the skull. Their number is generally limited to two or three; but they may be present in great numbers in the skulls of hydrocephalic subjects. They have no true morphological significance.

THE FACIAL BONES (OSSA FACIEI)

THE MAXILLÆ

The **maxillæ** are the largest bones of the face, excepting the mandible, and by their union form the whole of the upper jaw (fig. 297). Each assists in completing the roof of the mouth, the floor and lateral wall of the nasal cavity, and the floor of the orbit; it also enters into the formation of the infratemporal and pterygopalatine fossæ, and the inferior orbital and pterygopalatine fissures.

Each maxilla consists of a body and four processes—zygomatic, frontal, alveolar, and palatine.

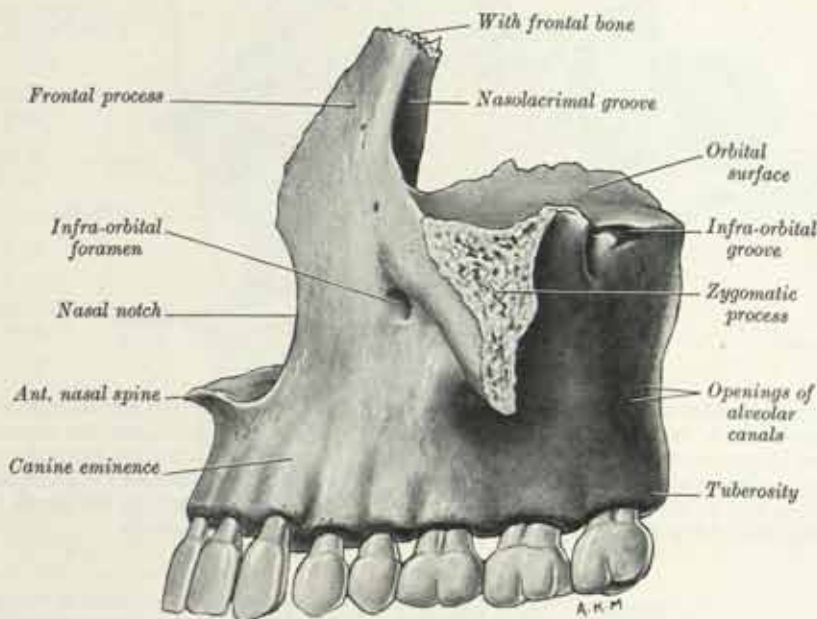
The **body** of the maxilla is pyramidal in shape. It has four surfaces—anterior, infratemporal (or posterior), orbital and nasal—and enclose a large cavity, termed the maxillary sinus.

The **anterior surface** (fig. 361) is directed forwards and laterally. Its lower part displays a number of slight elevations, which correspond to the positions of the roots of the upper teeth. Above those of the incisor teeth there is a slight depression, named the *incisive fossa*, which gives origin to the depressor septi; to the alveolar border below the fossa a slip of the orbicularis oris is attached; above and lateral to the fossa, the compressor naris muscle arises. Lateral to the incisive fossa there is a larger and deeper depression, named the *canine fossa*; it is separated from the incisive fossa by the *canine eminence*, which corresponds to the socket of the canine tooth; the fossa gives origin to the levator anguli oris muscle. Above the canine fossa the *infra-orbital foramen* marks the anterior end of the infra-orbital canal; it transmits the infra-orbital vessels and nerve. Above the foramen a sharp border marks the junction of

the anterior and orbital surfaces. This border forms a small part of the circumference of the orbital opening, and gives origin to the levator labii superioris. On the medial side, the anterior surface is limited by a deep concavity, termed the *nasal notch*; the margin of the notch gives attachment to the dilator naris and ends below in a pointed process which, with the corresponding process of the opposite maxilla, forms the *anterior nasal spine*.

The *infratemporal surface* (fig. 361) is convex, directed backwards and laterally, and forms the anterior wall of the infratemporal fossa. It is separated from the anterior surface by the zygomatic process and by a ridge which runs upwards to that process from the socket of the first molar tooth. It presents near its centre the apertures of two or three *alveolar canals*, which transmit the posterior superior dental vessels and nerves. At the lower and posterior part of this surface there is a round eminence, termed the *maxillary tuberosity*, which is rough on the upper part of its medial aspect for articulation with the pyramidal process of the palatine bone (fig. 363); it gives origin to a few fibres of the medial pterygoid muscle and, in some cases, articulates with the lateral pterygoid plate of the sphenoid bone. Above this a smooth

FIG. 361.—The left maxilla. Lateral aspect.



surface forms the anterior boundary of the pterygopalatine fossa and is grooved for the maxillary nerve; the groove for this nerve is directed laterally and slightly upwards and is continuous with the infra-orbital groove on the orbital surface.

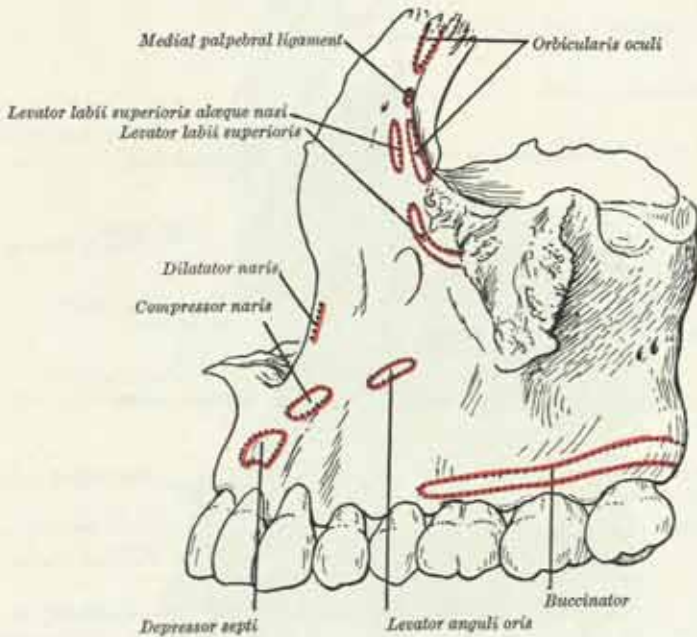
The *orbital surface* (fig. 361) is smooth and triangular, and forms the greater part of the floor of the orbit. Its *medial border* presents anteriorly a notch, termed the *lacrimal notch*, behind which it articulates from before backwards with the lacrimal bone, the orbital plate of the ethmoid, and the orbital process of the palatine bone (fig. 364). Its *posterior border* is smooth and rounded; it forms the greater part of the anterior margin of the inferior orbital fissure, and its middle part is notched by the commencement of the infra-orbital groove. The *anterior border* forms a small part of the circumference of the orbital opening and is continuous medially with the lacrimal crest on the frontal process (p. 344). The *infra-orbital groove*, for the passage of the infra-orbital vessels and nerve, begins at the middle of the posterior border, where it is continuous with the groove near the upper edge of the posterior surface; it passes forwards and ends in the *infra-orbital canal*, which opens on the anterior surface of the bone just below the infra-orbital margin. Near its midpoint the canal gives off a small branch from its lateral side for the passage of the anterior superior alveolar nerve and vessels. This small canal, often termed the *canalis sinuosus*,* passes forwards and downwards in the floor of the orbit lateral to the infra-orbital canal and then curves medially in the anterior wall of the maxillary sinus, passing below the infra-orbital foramen. Reaching the margin of the anterior nasal aperture just in front of the

* F. Wood Jones, *J. Anat.*, 73, 1939.

anterior end of the inferior concha, it then follows the lower margin of the aperture and opens at the side of the nasal septum in front of the incisive canal. At the medial and front part of the orbital surface, and lateral to the lacrimal groove, the origin of the inferior oblique muscle of the eyeball may be marked by a small depression.

The *nasal surface* (fig. 363) presents in its upper and posterior part a large, irregular opening, termed the *maxillary hiatus*, which leads into the maxillary sinus. At the upper border of this aperture there are some broken air-sinuses, which, in the articulated skull, are closed by the ethmoid and lacrimal bones. Below the maxillary hiatus a smooth concave surface forms part of the inferior meatus of the nasal cavity, and behind it there is a rough surface for articulation with the perpendicular plate of the palatine bone; this rough surface is traversed by a groove, which begins near the middle of the posterior border, runs obliquely downwards and forwards, and is converted into the *greater palatine canal* by the perpendicular plate of the palatine bone. In front of the maxillary hiatus a deep groove which is continuous above with the groove on the lacrimal bone (p. 338), constitutes about two-thirds of the circumference of the nasolacrimal canal, the remaining one-third being formed by the

FIG. 362.—Outline of left maxilla, showing muscular attachments.



descending part of the lacrimal bone and the lacrimal process of the inferior nasal concha (fig. 362); this canal opens into the inferior meatus of the nose (fig. 351) and transmits the nasolacrimal duct. More anteriorly the bone is marked by an oblique ridge, termed the *conchal crest*, for articulation with the inferior nasal concha. The shallow concavity below this ridge forms part of the inferior meatus of the nose, and the surface above the ridge part of the atrium of the middle meatus.

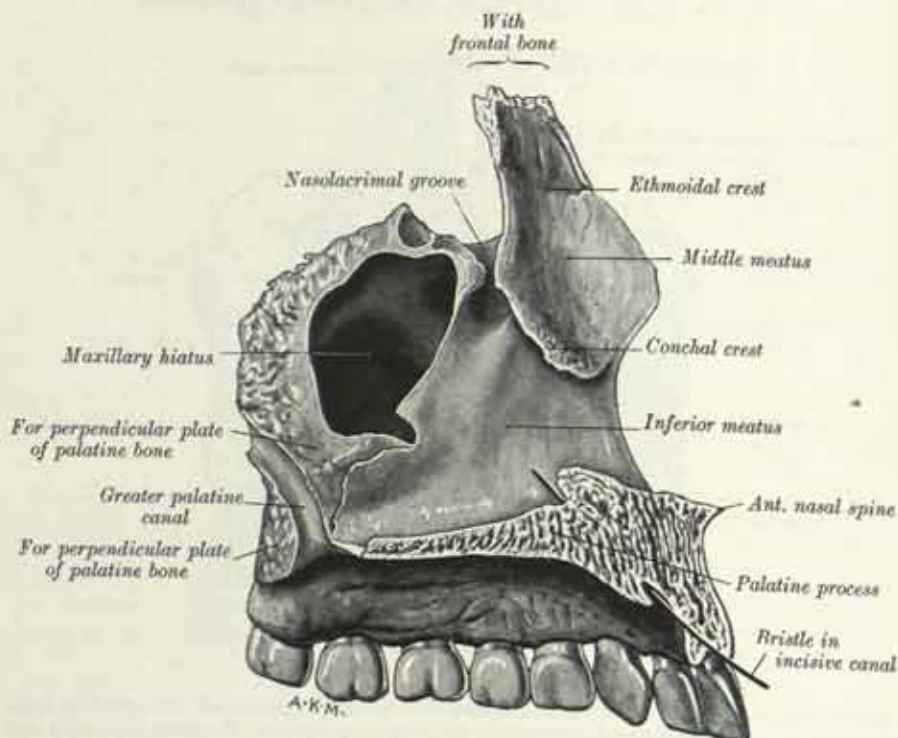
The **maxillary sinus** (figs. 363, 364) is a large pyramidal cavity within the body of the maxilla. Its walls are thin and correspond to the nasal, orbital, anterior and infratemporal surfaces of the body of the bone. Its *apex*, which is directed laterally, is formed by the zygomatic process; its *base*, or nasal wall, which faces medially, is formed by the lateral wall of the nasal cavity and presents the maxillary hiatus in the disarticulated bone. In the articulated skull this aperture is much reduced in size by the following bones: the uncinat process of the ethmoid and the descending part of the lacrimal bone above, the maxillary process of the inferior nasal concha below, and the perpendicular plate of the palatine bone behind (figs. 351, 364). The maxillary sinus communicates with the middle meatus of the nose, generally by two small apertures, one of which is usually closed by mucous membrane in the recent state. The *posterior wall* is pierced by the *alveolar canals*, which transmit the posterior superior alveolar vessels and nerves to the molar teeth; these canals occasionally project ridges into the maxillary sinus. The floor is formed by the alveolar process of the maxilla, and its lowest part is usually about 1.25 cm. below the level of the floor of the nasal cavity. In a large proportion of bones radiating septa of varying sizes

spring from the floor of the sinus in the intervals between the adjacent teeth ; in some cases the floor is perforated by the fangs of the molar teeth.* The infra-orbital canal usually projects into the sinus a well-marked ridge extending from the *roof* to the *anterior wall*. The size of the cavity varies in different skulls, and even on the two sides of the same skull.†

Applied Anatomy.—The extreme thinness of the walls of this cavity affords an explanation of the fact that a tumour growing from the maxillary sinus and encroaching upon the adjacent parts may push up the floor of the orbit, and displace the eyeball ; may project into the nose ; may protrude forwards on to the cheek ; or may make its way backwards into the infratemporal fossa, or downwards into the mouth.

The **zygomatic process** is a rough, pyramidal projection, situated at the angle of separation of the anterior, infratemporal and orbital surfaces. *In front* it forms part of the anterior surface of the body of the bone ; *behind*, it is concave, and continuous

FIG. 363.—The left maxilla. Medial aspect.



with the infratemporal surface ; *above*, it is rough and serrated for articulation with the zygomatic bone ; *below*, it presents an arched border, which separates the anterior from the infratemporal surface.

The **frontal process** projects upwards and backwards between the nasal and lacrimal bones (figs. 303, 364). Its *lateral surface* (fig. 361) is divided by a vertical ridge, termed the *anterior lacrimal crest*, which gives attachment to the medial palpebral ligament and is continuous below with the infra-orbital margin. At the junction of the crest with the orbital surface there is a small tubercle, which serves as a guide to the position of the lacrimal sac. The part in front of the lacrimal crest is smooth and merges below with the anterior surface of the body ; it gives attachment to a portion of the orbicularis oculi and to the levator labii superioris alicque nasi. Behind the anterior lacrimal crest there is a vertical groove which assists the groove on the lacrimal bone to complete a fossa for the lodgement of the lacrimal sac.

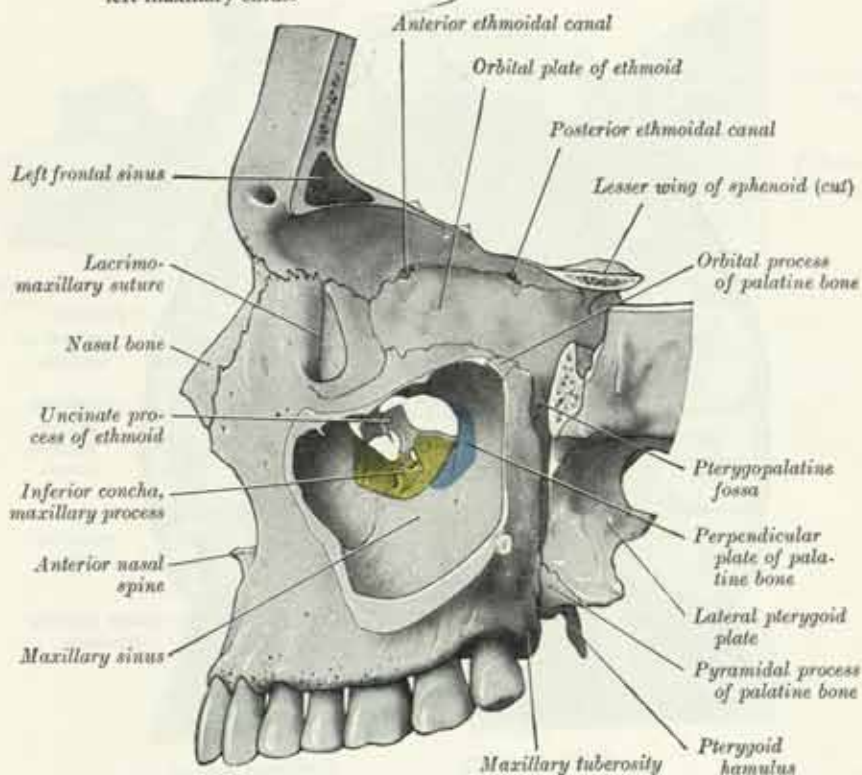
* The number of teeth whose roots are in relation with the floor of the maxillary sinus is variable. The sinus may extend so as to be in relation to all the teeth of the true maxilla, from the canine to the third molar.—(Salter.)

† Logan Turner (*op. cit.* p. 315) gives the following measurements for an adult sinus of average size : vertical height opposite first molar tooth, 3.5 cm. ; transverse breadth, 2.5 cm., and anteroposterior depth, 3.2 cm.

The *medial surface* of the frontal process (fig. 363) forms a portion of the lateral wall of the nasal cavity. A rough, uneven area at its upper part articulates with the ethmoid bone and closes the anterior ethmoidal cellules. Below this rough area there is an oblique ridge, termed the *ethmoidal crest*, the posterior part of which articulates with the middle nasal concha, while the anterior part underlies the agger nasi on the lateral wall of the nasal cavity; the ethmoidal crest forms the upper limit of the atrium of the middle meatus of the nose. The *upper end* of the frontal process articulates with the nasal part of the frontal bone, the *anterior border* with the nasal bone, and the *posterior border* with the lacrimal bone.

The *alveolar process* of the maxilla is thick and arched, broader behind than in front, and excavated to form sockets for the reception of the roots of the teeth. These cavities are eight in number and vary in size and depth according to the teeth they contain. That for the canine tooth is the deepest; those for the molars are the widest,

FIG. 364.—Oblique parasagittal section through the anterior part of the skull, showing the medial wall of the left orbit and the medial wall of the left maxillary sinus.



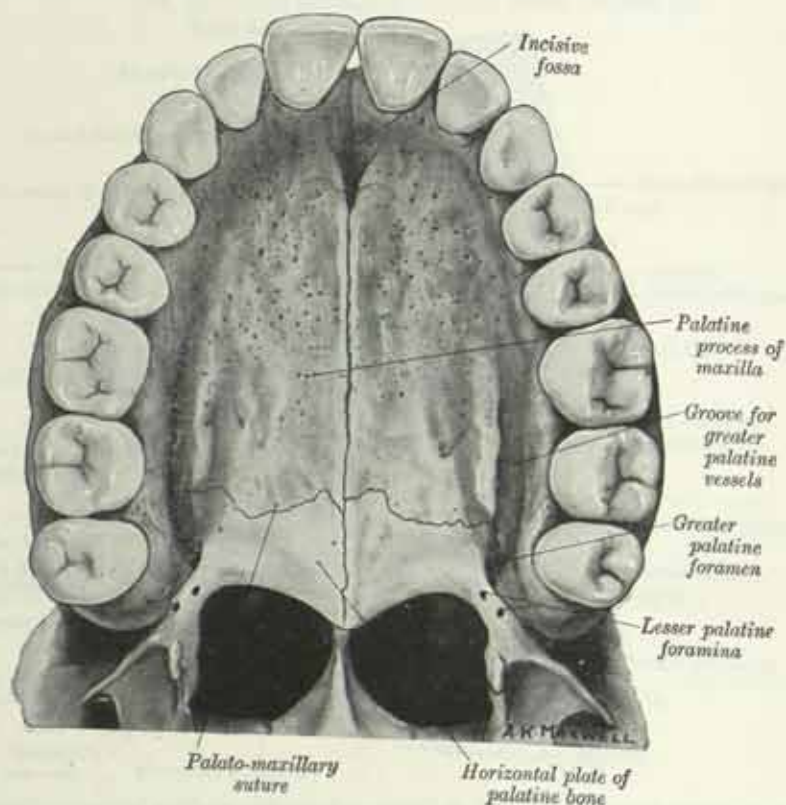
The inferior concha is shown in yellow and the perpendicular plate of the palatine bone in blue.

and are subdivided into three minor sockets by septa; those for the incisors and the second premolar are single; that for the first premolar is sometimes divided into two. The buccinator muscle arises from the outer surface of this process, as far forward as the first molar tooth. When the maxillæ are articulated with each other, their alveolar processes together form the *alveolar arch*.

The *palatine process* of the maxilla, which is thick and strong, is horizontal and projects medially from the lowest part of the nasal surface of the bone. It forms a considerable part of the floor of the nasal cavity and the roof of the mouth, and is much thicker in front than behind. Its *inferior surface* (fig. 365) is concave, rough and uneven, and forms, with the palatine process of the opposite bone, the anterior three-fourths of the bony palate. It is marked by numerous foramina for the passage of the nutrient vessels and presents depressions for the lodgement of the palatine glands; it is channelled at the posterior part of its lateral border by two grooves, which lodge the greater palatine vessels and nerve. When the two maxillæ are articulated, a funnel-shaped depression, termed the *incisive fossa*, is seen in the median plane, immediately behind the incisor teeth. In this opening the orifices of two lateral canals are visible: they are named the *incisive canals*; each leads upwards into the corresponding half of

the nasal cavity and transmits the terminal branch of the greater palatine artery and the nasopalatine nerve. Occasionally there are two additional apertures in the median plane; they are termed the *anterior* and *posterior incisive foramina*, and, when present, transmit the nasopalatine nerves, the left passing through the anterior, and the right through the posterior foramen. On the under surface of the palatine process, a delicate suture termed the *incisive suture*, well seen in young skulls, may sometimes be noticed extending laterally and forwards from the incisive fossa to the interval between the lateral incisor and the canine teeth. The small part in front of this suture constitutes the *os incisivum* (premaxilla), which in most vertebrates forms an independent bone. The upper surface of the palatine process is concave from side to side, smooth, and forms the greater part of the floor of the nasal cavity; close to the anterior part of its medial margin the bone is pierced by the upper orifice of the incisive canal. The lateral border of the process is fused with the rest of the bone. The medial

FIG. 365.—The bony palate and the alveolar arch. Inferior aspect.



border, thicker in front than behind, is raised into a ridge, termed the *nasal crest*, which, with the corresponding ridge of the opposite bone, forms a groove for the reception of the vomer. The front part of this ridge rises to a considerable height and is sometimes named the *incisor crest* (fig. 363); it is prolonged forwards into a sharp process, which with the similar process of the opposite bone, forms the *anterior nasal spine*. The posterior border is serrated for articulation with the horizontal plate of the palatine bone.

Ossification.—The maxilla is developed in membrane from two principal centres,* one for the maxilla proper and one for the *os incisivum*. These centres appear about the end of the sixth week of intrauterine life, that for the maxilla above the canine tooth-germ, and that for the *os incisivum* above the incisor tooth-germs. The *os incisivum* develops in the median nasal process (p. 111) but, as a result of the invasion of that process by the mesenchyme of the maxillary process (p. 111), the *os incisivum* takes no part in the formation of the labial walls of the incisor sockets, although it can still be identified in the child at the lower margin of the anterior nasal aperture.†

* F. P. Mall, *Amer. J. Anat.*, 5, 1906, and E. Fawcett, *J. Anat. and Physiol.*, 45, 1911.

† E. H. Johnson, *J. Anat.*, 71, 1937.

On the palate, however, the suture line between the os incisivum and the maxilla runs from the septum between the canine and the lateral incisor tooth to the incisive fossa. It can readily be identified at birth (fig. 367) and may occasionally persist until nearly middle life. At a later stage an additional centre (*prevomerine* or *paraseptal centre*) appears for the os incisivum on the medial side of the corresponding paraseptal cartilage. The maxillary sinus appears as a shallow groove (fig. 368) on the nasal surface of the bone about the fourth month of intrauterine life, but does not reach its full size until after the second dentition. The infra-orbital vessels and nerve lie for a time in a groove in the floor of the orbit; the anterior part of this groove is converted into the infra-orbital canal by a lamina of bone which grows from the lateral side of the groove.

FIG. 366.—The right maxilla at birth.
Lateral aspect.

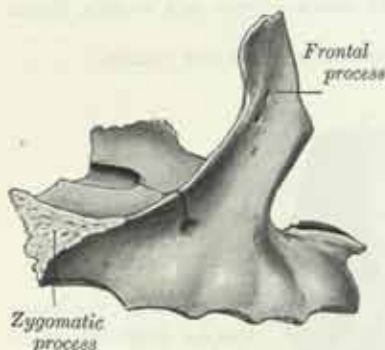


FIG. 367.—The right maxilla at birth.
Inferior aspect.

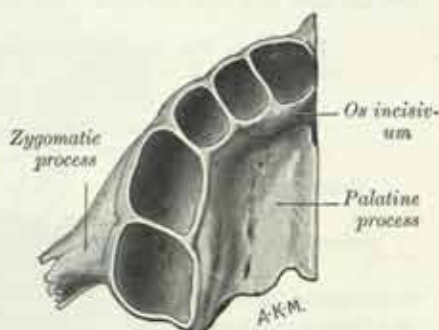
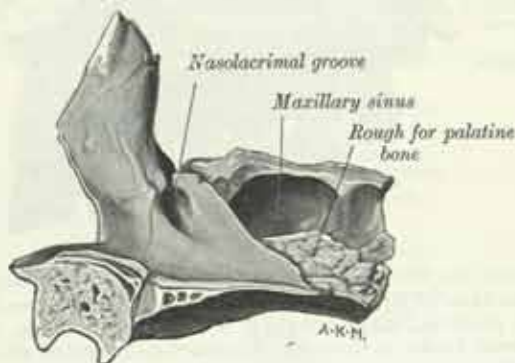


FIG. 368.—The right maxilla at birth. Medial aspect.



CHANGES PRODUCED IN THE MAXILLA BY AGE

At birth the transverse and anteroposterior diameters of the maxilla are each greater than the vertical. The frontal process is well-marked, but the body of the bone consists of little more than the alveolar process, the tooth-sockets reaching almost to the floor of the orbit. The maxillary sinus is seen as a furrow on the lateral wall of the nose. In the adult the vertical diameter is the greatest, owing to the development of the alveolar process and the increase in size of the sinus. In old age the bone reverts in some measure to the infantile condition: its height is diminished and, after the loss of the teeth, the alveolar process is absorbed (p. 309) and the lower part of the bone contracted and reduced in thickness* at the expense of the labial wall. The differences in the way in which the alveolar processes are absorbed in the maxilla and in the mandible are of considerable practical importance in the provision of dentures (p. 309).

* See references in footnotes on p. 309.

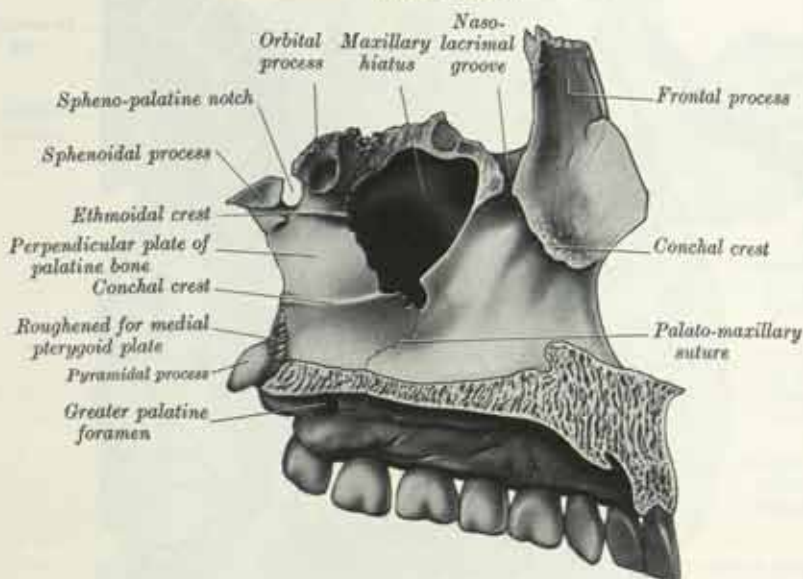
THE PALATINE BONES

The **palatine bones** are situated at the posterior part of the nasal cavity, between the maxillæ and the pterygoid processes of the sphenoid bone (fig. 351). Each assists in forming the floor and lateral wall of the nasal cavity, the roof of the mouth, and the floor of the orbit, and enters into the formation of the pterygopalatine and pterygoid fossæ and the inferior orbital fissure.

The palatine bone bears some resemblance to the letter **L**, and consists of a horizontal and a perpendicular plate, and three processes—viz. the pyramidal process (tubercle), which is directed backwards, laterally and downwards from the junction of the horizontal and perpendicular plate, and the orbital and sphenoidal processes, which surmount the perpendicular plate and are separated by a deep notch, named the sphenopalatine notch.

The **horizontal plate** of the palatine bone (figs. 309, 371) is quadrilateral and has two surfaces and four borders. The *nasal surface*, concave from side to side, forms

FIG. 369.—The left palatine bone in articulation with the left maxilla. Medial aspect.



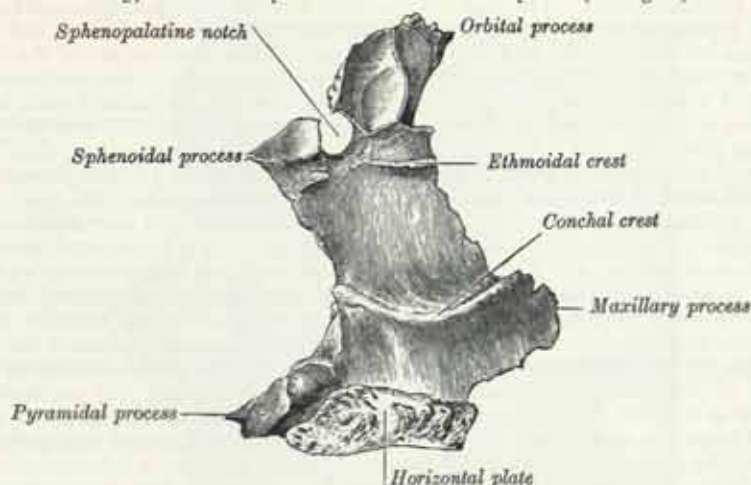
the posterior part of the floor of the nasal cavity. The *palatine surface* forms, with the corresponding surface of the opposite bone, the posterior one-fourth of the bony palate; near its posterior margin there is often a curved ridge, termed the *palatine crest*. The *posterior border* is thin and concave; to it, and to the palatine surface as far forwards as the palatine crest, the expanded tendon of the tensor veli palatini is attached. The medial end of the posterior border is pointed and, when united with that of the opposite bone, forms a projecting process, which gives attachment to the musculus uvulæ, and is named the *posterior nasal spine*. The *anterior border* is serrated and articulates with the palatine process of the maxilla. The *lateral border* is continuous with the inferior border of the perpendicular plate and is marked at the lower end by the greater palatine groove. The *medial border*, which is thick and serrated, articulates with the corresponding border of the opposite bone, and the opposed borders form the posterior part of the *nasal crest*. This crest articulates with the posterior part of the lower edge of the vomer and is continuous anteriorly with the nasal crest of the maxillæ.

The **perpendicular plate** of the palatine bone (figs. 370, 371) is thin and of an oblong form, and has two surfaces and four borders.

The *nasal (or medial) surface* exhibits at its lower part a broad, shallow depression which forms part of the inferior meatus of the nasal cavity. Immediately above this the *conchal crest* forms a horizontal ridge for articulation with the inferior nasal concha; still higher there is a second broad, shallow depression, which forms part of the middle meatus and is limited above by the *ethmoidal crest* for articulation with the middle nasal concha. Above the ethmoidal crest there is a narrow, horizontal groove, which forms part of the superior meatus.

The *maxillary* or *lateral surface* is rough and irregular throughout the greater part of its extent, for articulation with the nasal surface of the maxilla; its upper and posterior part is smooth and forms the medial wall of the pterygopalatine fossa; its front portion, which is also smooth, projects beyond the posterior border of the

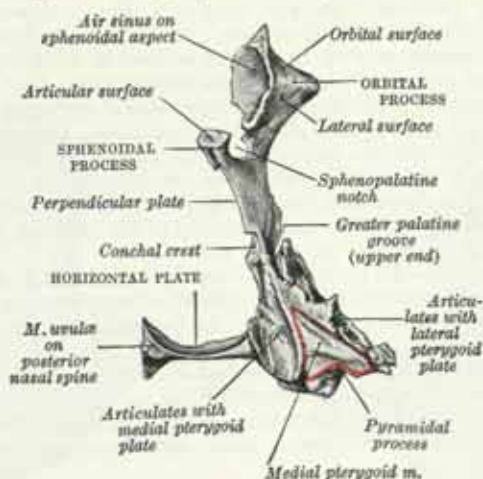
FIG. 370.—The left palatine bone. Medial aspect. (Enlarged.)



maxillary hiatus and forms the posterior part of the medial wall of the maxillary sinus (fig. 364). On the posterior part of the maxillary surface there is a deep vertical groove, named the *pterygopalatine groove* (*greater palatine groove*), which in the articulated skull is converted into the *greater palatine canal* by the maxilla; this canal transmits the greater palatine vessels and nerves.

The *anterior border* is thin and irregular; at the level of the conchal crest a pointed, projecting lamina is directed forwards below and behind the maxillary

FIG. 371.—The right palatine bone. Posterior aspect.



process of the inferior nasal concha. It articulates with the latter and assists in forming the medial wall of the maxillary sinus (fig. 364). The *posterior border* (fig. 371) is serrated for articulation with the medial pterygoid plate of the sphenoid bone. This border is continuous above with the sphenoidal process; it expands below into the pyramidal process of the palatine bone. The *superior border* supports the orbital process in front and the sphenoidal process behind. These processes are separated by the *sphenopalatine notch*, which is converted into the *sphenopalatine foramen* by the under surface of the body of the sphenoid. In the articulated skull this foramen leads from the pterygopalatine fossa into the posterior part of the superior meatus of the nose, and transmits the sphenopalatine vessels and nasopalatine nerve. The *inferior border* is continuous with the lateral border of the

horizontal plate and, in front of the pyramidal process, is marked by the lower end of the pterygopalatine groove.

The **pyramidal process** of the palatine bone projects backwards, laterally, and downwards from the junction of the horizontal and perpendicular plates of the bone, and fits into the angular interval between the lower ends of the pterygoid plates. On its *posterior surface* there is a smooth, grooved triangular area, limited on each side by a rough articular furrow. The furrows articulate with the pterygoid plates, while the grooved triangular area completes the lower part of the pterygoid fossa and gives origin to some fibres of the medial pterygoid muscle. The anterior part of the *lateral surface* is rough for articulation with the maxillary tuberosity; the posterior part consists of a smooth triangular area, which appears, in the articulated skull, at the lower part of the infratemporal fossa between the maxillary tuberosity and the lateral pterygoid plate (fig. 306). The *inferior surface* of the pyramidal process, close to its union with the horizontal plate of the bone, presents the *lesser palatine foramina* for the transmission of the lesser (middle and posterior) palatine nerves (fig. 309).

The **orbital process** (figs. 370, 371) is directed upwards and laterally from the front of the perpendicular plate, to which it is joined by a constricted neck. It encloses an air-sinus, and presents three articular and two non-articular surfaces. Of the articular surfaces: (1) the *anterior or maxillary*, of an oblong form, is directed forwards, laterally, and downwards, and articulates with the maxilla; (2) the *posterior or sphenoidal*, directed backwards, upwards, and medially, presents the opening of the air-sinus, which usually communicates with the sphenoidal sinus; the margins of the opening articulate with the sphenoidal concha; (3) the *medial or ethmoidal* is directed medially and forwards, and articulates with the labyrinth of the ethmoid bone. In some cases, the air-sinus opens on this surface and then communicates with the posterior ethmoidal cellules; more rarely it opens on the ethmoidal and sphenoidal surfaces, and then communicates with the posterior ethmoidal cellules and the sphenoidal sinus. Of the non-articular surfaces: (1) the *superior or orbital*, triangular in shape, is directed upwards and laterally, and forms the posterior part of the floor of the orbit (fig. 313); and (2) the *lateral*, of an oblong form, is directed towards the pterygopalatine fossa and is separated from the orbital surface by a rounded border, which forms the medial part of the lower margin of the inferior orbital fissure; the lower part of this surface may present a groove, directed laterally and upwards, which lodges the maxillary nerve and is continuous with the groove on the upper part of the posterior surface of the maxilla (p. 342). The border between the lateral and posterior surfaces is prolonged downwards as the anterior boundary of the sphenopalatine notch.

The **sphenoidal process** (figs. 370, 371) is a thin, compressed plate, smaller and on a lower level than the orbital process; it is directed upwards and medially. Its *superior surface* articulates with the under surface of the sphenoidal concha and the root of the medial pterygoid plate; it presents a groove which contributes to the formation of the palatinovaginal canal. The *inferomedial surface* is concave and forms a small part of the roof and lateral wall of the nasal cavity. The posterior part of the *lateral surface* articulates with the medial pterygoid plate; the anterior part is smooth and forms a portion of the medial wall of the pterygopalatine fossa. The *posterior border* is rough and articulates with the vaginal process of the medial pterygoid plate. The *anterior border* forms the posterior boundary of the sphenopalatine notch. The *medial border* articulates with the ala of the vomer.

The orbital and sphenoidal processes are separated from each other by the *sphenopalatine notch*, which is converted into the sphenopalatine foramen by the under surface of the body of the sphenoid; sometimes the two processes are united by a spicule of bone which converts the notch into a foramen.

Ossification.—The palatine bone is ossified in membrane from one centre, which appears during the eighth week of intrauterine life in the perpendicular plate of the bone. From this point ossification spreads upwards into the orbital and sphenoidal processes, medially into the horizontal plate, and downwards into the pyramidal process.

At the time of birth the height of the perpendicular plate is about equal to the transverse width of the horizontal plate, whereas in the adult it measures nearly twice as much.

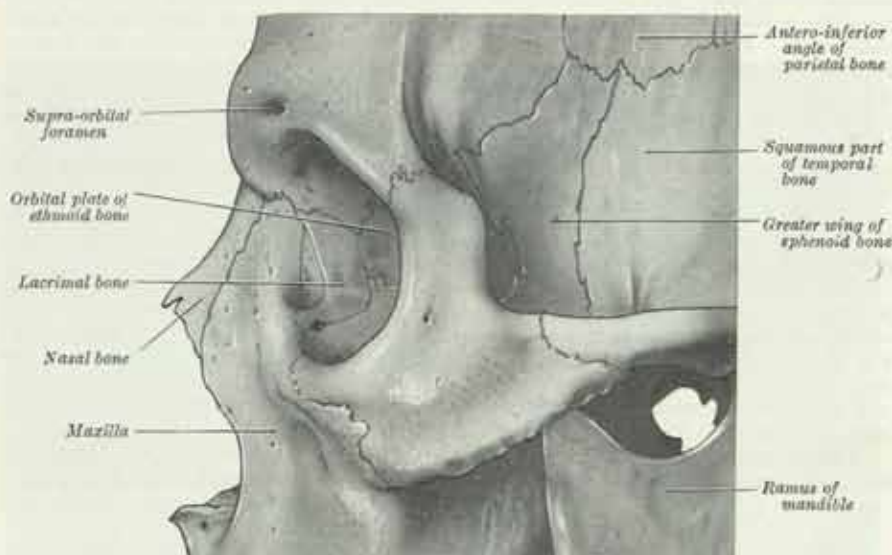
THE ZYGOMATIC BONES

The **zygomatic bones** are situated in the upper and lateral parts of the face. Each forms the prominence of the cheek, and contributes to the formation of the lateral wall and floor of the orbit and to the walls of the temporal and infratemporal fossæ (fig. 372).

The zygomatic bone is quadrangular in shape, but has a flange-like projection from the anterior part of its medial aspect. It has three surfaces, five borders and two processes.

The *malar surface (lateral surface)* (figs. 372, 373) directed laterally and forwards, is convex and is pierced near its orbital border by the *zygomaticofacial foramen* (which is often double), for the passage of the zygomaticofacial nerve and vessels; below this foramen a slight elevation gives origin to the *zygomaticus minor* and more posteriorly

FIG. 372.—The left zygomatic bone *in situ*.



the *zygomaticus major* takes origin. The *temporal surface* (fig. 374), which is directed medially and backwards, is concave. It presents anteriorly a roughened area for articulation with the maxilla, and posteriorly a smooth, concave area which extends upwards on the posterior aspect of the frontal process to form the anterior boundary of the temporal fossa. It also extends backwards on the medial aspect of the temporal

FIG. 373.—The left zygomatic bone. Lateral aspect.

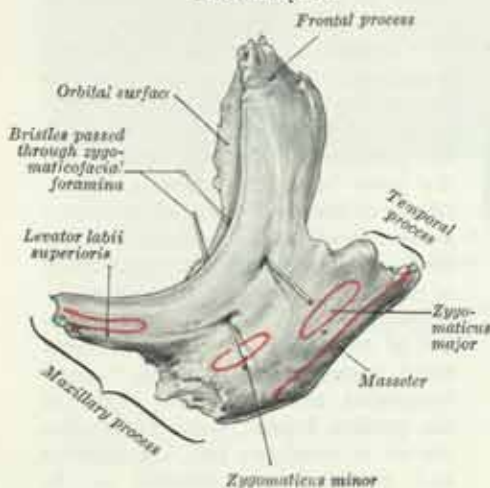
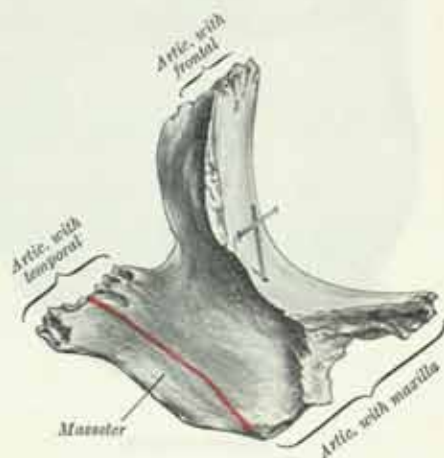


FIG. 374.—The left zygomatic bone. Medial aspect.



process to form an incomplete lateral wall for the infratemporal fossa. The *zygomatico-temporal foramen*, for the transmission of the nerve of the same name, pierces this surface near the base of the frontal process. The *orbital surface* (fig. 374), smooth and concave, forms the anterolateral part of the floor and the adjoining part of the lateral wall of the orbit, extending upwards on to the medial aspect of the frontal process. It usually presents the orifices of two canals, termed the *zygomatico-orbital foramina*, one of which leads to the zygomaticofacial and the other to the zygomatico-temporal foramen.

The *anterosuperior* or *orbital border* is smooth and concave, and forms a considerable part of the circumference of the orbital opening, below and on the lateral side. It separates the orbital from the lateral surface. The *antero-inferior* or *maxillary border* is rough and articulates with the maxilla; its medial extremity is pointed and lies above the infra-orbital foramen; near the orbital margin it gives origin to a part of the levator labii superioris. The *posterosuperior* or *temporal border* is curved, being convex in its upper and concave in its lower part, and is continuous above with the posterior border of the frontal process and below with the upper border of the zygomatic arch; it gives attachment to the temporal fascia. A little below the fronto-zygomatic suture this border frequently presents a small, rounded projection, termed the *marginal tubercle*, which can be felt easily through the skin. The *postero-inferior border* affords attachment by its rough edge to the masseter muscle. The *postero-medial border* is serrated for articulation with the greater wing of the sphenoid above, and the orbital surface of the maxilla below. Between these two serrated portions there is usually a short, concave, nonarticular part, which forms the lateral boundary of the inferior orbital fissure. This nonarticular part is sometimes absent, and the fissure is then completed by the junction of the maxilla and the sphenoid bone, or by the interposition of a small sutural bone in the angular interval between them.

The *frontal process* is thick and serrated; it articulates above with the zygomatic process of the frontal bone and behind with the greater wing of the sphenoid. On its orbital aspect, just within the orbital opening and about 1 cm. below the fronto-zygomatic suture, there is a tubercle of varying size and form, but present in 95 per cent. of skulls (Whitnall).* The *temporal process* is directed backwards and ends in an oblique, serrated margin which articulates with the zygomatic process of the temporal bone, and helps to form the zygomatic arch.

Ossification.—The zygomatic bone is ossified from one centre, which appears about the eighth week of intrauterine life. The bone is sometimes divided by a horizontal suture into an upper larger, and a lower smaller division.

FIG. 375.—The skull of a new-born child.
Superior aspect.

Anterior fontanelle



Posterior fontanelle

THE DIFFERENCES IN THE SKULL DUE TO AGE

At birth the skull is large in proportion to the other parts of the skeleton, but the base is short and narrow in proportion to the vault; the facial portion is small and equals only about one eighth of the size of the cranium as compared with one-half in the adult. The frontal and parietal tubera are prominent, and when the skull is viewed from above it presents a pentagonal outline with its greatest width at the parietal tubera (fig. 375); on the other hand, the glabella, superciliary arches, and mastoid processes are not developed. Ossification of the skull bones is not completed, and many of them—e.g. the occipital, temporals, sphenoid, frontal, and mandible—consist of more than one piece. Unossified membranous intervals, termed *fontanelles*, are seen at the angles of the parietal bones; these fontanelles are six in number; two, the anterior and posterior, are situated in the

median plane, and two, the anterolateral and posterolateral, on each side.

The *anterior fontanelle* (fig. 375) is the largest, and is placed at the junction of the sagittal, coronal, and frontal sutures; it is lozenge-shaped, and measures about 4 cm. in its anteroposterior and 2.5 cm. in its transverse diameter. The

* S. E. Whitnall, *The Anatomy of the Human Orbit*, 1921.—The structures attached to this tubercle are: (1) the 'check ligament' of the rectus lateralis; (2) part of the sponeurosis of the levator palpebrae superioris; (3) the suspensory ligament of the eyeball; and (4) the lateral palpebral ligament.

PLATE VII



Radiograph of the right shoulder, in a boy, aged 11. Antero-posterior view.

Note the wide gap between the lateral end of the bone of the clavicle and the acromion; it is occupied by cartilage, not yet ossified, and by the acromio-clavicular joint, which cannot yet be identified.

1. Coracoid process. 2. Epiphyseal plate at upper end of humeral diaphysis.
3. Acromion. 4. Lateral end of clavicle, not yet completely ossified.



FIG. 1.—Radiograph of adult elbow. Frontal view. The shadow of the olecranon extends upwards to the olecranon fossa and obscures the outline of the trochlea. The gap between the humerus and the bones of the forearm is occupied by the articular cartilage of the bones concerned.



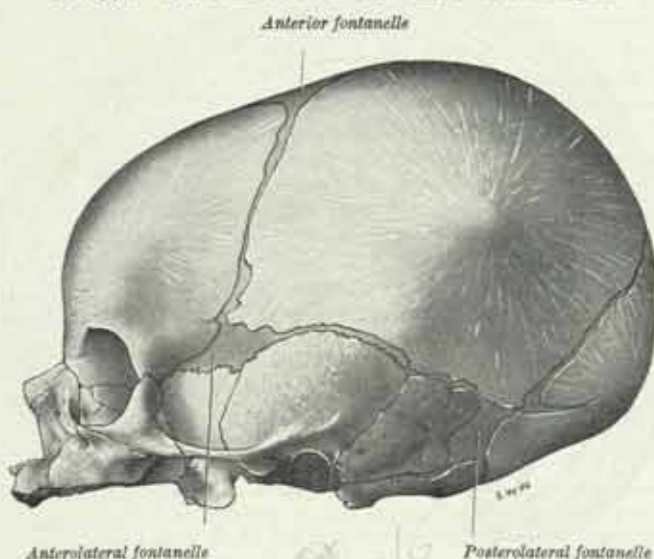
FIG. 2.—Radiograph of the elbow of a child, aged 11 years. Frontal view. The upper epiphysis of the radius, the epiphysis for the medial epicondyle, and the centre for the capitulum and lateral part of the trochlea can be recognised without difficulty.

posterior fontanelle (fig. 375) is triangular in form and is situated at the junction of the sagittal and lambdoid sutures. The anterolateral and posterolateral fontanelles (fig. 376) are small, irregular in shape, and correspond respectively with the sphenoidal and mastoid angles of the parietal bones.

The fontanelles are usually closed by the growth and extension of the bones which surround them, but sometimes they are the sites of separate centres of ossification which develop into sutural bones. The posterior and anterolateral fontanelles are obliterated within two or three months after birth; the posterolateral fontanelle is usually closed about the end of the first year, and the anterior fontanelle about the middle of the second year.

The smallness of the face at birth can be attributed to the rudimentary condition of the mandible and maxillæ, the non-eruption of the teeth, and the small size of the maxillary sinuses and nasal cavity. At birth the nasal cavity lies almost entirely between the orbits, and the lower border of the anterior nasal aperture is only a little below the level of the orbital floor. With the eruption of the deciduous teeth there is an enlargement of the face and jaws, and these changes are still more marked after the second dentition.

FIG. 376.—The skull of a new-born child. Lateral aspect.



The skull grows rapidly from birth to the seventh year, but the greater part of the increase of its cranial part occurs during the first year owing to the rapidity of the growth of the brain in that period (p. 143). In the base, *growth in length* occurs at the cartilaginous joints between the sphenoid, on the one hand, and the ethmoid and occipital bones on the other, but more especially at the latter. In the vault *growth in length* occurs at the coronal and lambdoid sutures. *Growth in breadth* occurs at the sagittal and metopic (p. 333) sutures in the vault, and at the lower parts of the suture between the greater wing of the sphenoid and the squamous temporal, and at the occipito-mastoid suture and the petro-occipital cartilaginous joint in the base. *Growth in height* occurs at the fronto-zygomatic suture, the pterion (p. 329), the squamosal suture and the asterion (p. 330).

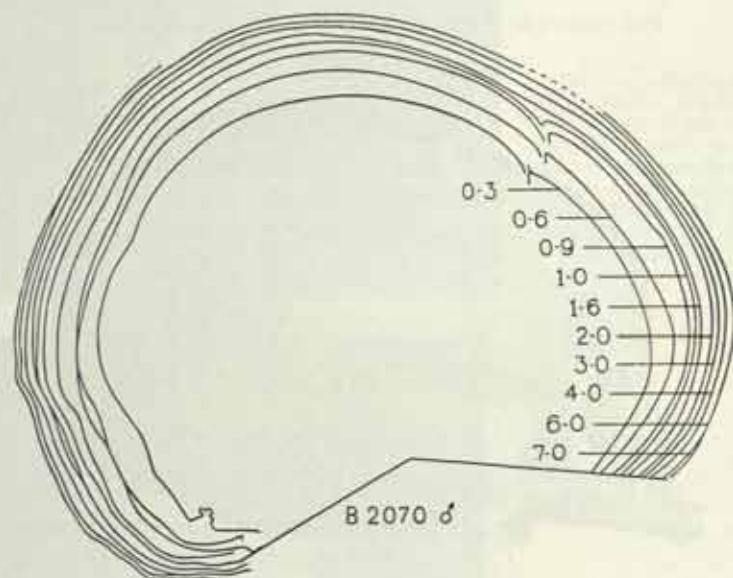
The presence of the fontanelles allows for the initial period of very rapid growth and after their closure growth continues in the fibrous tissue of the sutural ligaments. Sections through the sutures in young skulls reveal the fact that the fibrous tissue along the middle of the sutural membrane remains highly cellular* but on each side it consists of parallel bundles of collagenous fibres which penetrate the sutural margins of the bones, forming Sharpey's fibres (p. 25). Appositional growth occurs

* A. G. Brodie, *Amer. J. Anat.*, 68, 1941; J. P. Weinmann and Harry Sicher, *Bone and Bones*. Henry Kimpton, London, W.C. 1, 1947.

at these margins as long as the bones concerned continue to expand in surface extent. This sutural growth is not only sufficient to provide room for the expansion of the brain, but it is also sufficient to allow the bones to thicken by appositional growth on both surfaces. In the newly born the curvatures of the frontal and parietal bones, especially, are much sharper than they are in the adult (cf. fig. 375 and fig. 296), but these bones become gradually flatter as they thicken—apposition being greater in amount on the cerebral surface where the curves are deepest—and so adapt themselves to the increasing growth of the brain in height.

Lateral X-ray photographs of the skull of the same child from the age of 6 months to 8 years,* superimposed with the centre of the hypophyseal fossa as an approximately fixed point, show that the expansion of the cranium results from, broadly speaking, concentric growth (fig. 377). It can be inferred that the general form of

FIG. 377.—Tracings of the outline of the skull of the same child made from lateral X-ray photographs taken at different ages between 3 months (0.3) and 7 years (7.0), as indicated in the figure. (Reproduced by the courtesy of Dr. A. G. Brodie and the Editor of the American Journal of Anatomy. *Am. J. Anat.*, 68, 1941.)



Note that the general shape of the skull has already been determined by the end of the third month, and observe the rapidity of growth up to the end of the ninth month. In tracing the outlines the centre of the hypophyseal fossa was used as an approximately fixed point.

the cranium remains unaltered so far as its outline is concerned, and is determined in the early part of the first year. Towards the end of the second year the mastoid process makes its appearance, and the tympanic ring begins to lengthen to form the bony part of the external acoustic meatus (p. 327). As a result the styloid process and the stylomastoid foramen, which are relatively superficial in the newly born child, become more deeply situated. At the seventh year the cribriform plate of the ethmoid bone, the foramen magnum, and the petrous parts of the temporal bones have reached their full size, and the orbits are only a little smaller than those of the adult. Growth is slow from the seventh year until the approach of puberty, when a second period of increased activity occurs: this results in an enlargement in all directions, but especially in the frontal and facial regions, where it is associated with the eruption of the permanent teeth and the correlated increase in size of the maxillary and frontal air-sinuses.

Obliteration of the sutures of the vault of the skull takes place as age advances. It may commence between the ages of thirty and forty on the inner surface, and

* A. G. Brodie, *Amer. J. Anat.*, 68, 1941; J. P. Weinman and Harry Sicher, *Bone and Bones*. Henry Kimpton, London, W.C. 1, 1947.

about ten years later on the outer surface of the skull, but the times at which the sutures close are subject to great variations. Obliteration usually occurs first in the lower part of the coronal suture, next in the posterior part of the sagittal suture, and then in the lambdoid suture.

In old age the skull generally becomes thinner and lighter, but in a small proportion of cases it increases in thickness and weight. The most striking feature of the senile skull is the diminution in the size of the mandible and maxillæ consequent on the loss of the teeth and the absorption of the alveolar processes. This is associated with a marked reduction in the vertical measurement of the face and with an alteration in the angles of the mandible (fig. 323) already described (p. 309).

THE SEX DIFFERENCES IN THE SKULL

Until the age of puberty there is little difference between the skulls of the two sexes. The skull of an adult female is as a rule lighter and smaller, and its capacity is about 10 per cent. less, than that of the male. Its walls are thinner and its muscular ridges less marked; the glabella, superciliary arches, and mastoid processes are less prominent, and the corresponding air-sinuses are small or rudimentary. The tympanic part of the temporal bone is smaller and its margins less roughened than in the male. The upper margin of the orbit is sharp, the forehead vertical, the frontal and parietal tubera prominent, and the vault somewhat flattened. The contour of the face is rounder, the facial bones are smoother, and the mandible and maxillæ and their contained teeth smaller. Speaking generally, more of the infantile characteristics are retained in the skull of the adult female. A well-marked male or female skull can easily be recognised as such, but in some skulls the characteristics are so indistinct that the determination of the sex may be difficult or impossible.*

Craniology. The skulls of the different races of men show variations in size and shape and their study constitutes the subject of craniology, which is a branch of anthropology. The details of the measurements used will be found elsewhere,† but it may be noted that the capacity of the cranial cavity necessarily gives a good indication of the size of the brain which it contained. The cranial capacity of the average male European exceeds 1450 c. cm. and is classified as *megacephalic*.

The proportion of breadth to length of skull, $\frac{\text{breadth} \times 100}{\text{length}}$, constitutes the *cephalic index*, and skulls are classed as *brachycephalic* when the index is above 80, as *mesati-cephalic* when the index is between 75 and 80, and as *dolichocephalic* when the index is below 75. Most European skulls fall into the middle group. Many other indices have been explored and their results tabulated.† They provide data concerning the shape of the orbital aperture, the nose, the forward projection of the jaws etc. for the different races.

Applied Anatomy.—The chief function of the skull is to protect the brain, and therefore those portions of the skull which are most exposed to external violence are thicker than those which are shielded from injury by overlying muscles. Thus, the skull-cap is thick and dense, whereas the squamous temporal, being protected by the temporal muscles, and the inferior occipital fossæ, being shielded by the muscles at the back of the neck, are thin and fragile. Additional features which tend to prevent fracture of the skull are its elasticity, its rounded shape, and its construction of a number of secondary elastic arches, each made up of a single bone.

The most common place for fracture of the base to occur is through the middle fossa, and here the fissure usually takes a fairly definite course. Starting from the point struck, which is generally somewhere in the neighbourhood of the parietal tuber, it runs downwards through the parietal and the squamous temporal and across the petrous portion (Pl. V), frequently traversing and implicating the internal acoustic meatus, to the foramen lacerum. The course of the fracture explains the symptoms to which fracture in this region may give rise: thus if the fissure passes across the internal acoustic meatus injury to the facial and eighth

* See F. G. Parsons and M. F. Lucas Keene, *J. Anat.*, 54, 1919.

† W. L. H. Duckworth, *Morphology and Anthropology*. Cambridge University Press, 2nd edition.

nerves may result, with consequent facial paralysis and deafness; if the fissure extends through the semicircular ducts giddiness will be complained of, especially on turning the head sideways; or the tubular prolongation of the arachnoid around the nerves in the meatus may be torn and thus permit of the escape of the cerebrospinal fluid, should there be a communication between the internal ear and the tympanic cavity together with rupture of the tympanic membrane, as is frequently the case.

The bones of the face are sometimes fractured as the result of direct violence. Those most commonly broken are the nasal bones and the mandible; the latter is by far the most frequently fractured of all the facial bones. Fracture of the *nasal bone* is for the most part transverse, and takes place about 1.25 cm. from the free margin. The broken portion may be displaced backwards or more generally to one side by the force which produced the lesion. The most common situation for a fracture of the *mandible* is in the neighbourhood of the canine tooth, as at this spot the bone is weakened by the deep socket for the root of this tooth; it is next most frequently fractured at the angle. Occasionally a double fracture may occur, one in each half of the bone. The fractures are usually compound, from laceration of the mucous membrane covering the gums.

THE LIMBS

The upper and lower limbs are constructed after a common type, but the different functions for which they have become adapted in man have led to structural differences of a very definite kind. Each limb has a girdle, which connects it to the trunk, and three segments. The terminal segment in the upper limb is the hand and is specially adapted for prehension. In the lower limb the terminal segment is the foot and is primarily adapted to constitute an efficient supporting base for the body in the erect attitude, but it is, at the same time, constructed in such a manner as to facilitate locomotion (p. 543). In order that the full benefit of the prehensile character of the hand may be obtained, the living upper limb is characterised by the wide range of movement which it enjoys—in some situations, e.g. the shoulder-joint, actually at the expense of stability. In the living lower limb, on the other hand, the demand for stability is the prime factor, and stability is assured, even although some degree of mobility may be sacrificed for the purpose.

The bones by which the upper and lower limbs are attached to the trunk constitute, respectively, the shoulder and pelvic girdles. The *shoulder girdle*, which is formed by the scapulae and the clavicles, is deficient both in front and behind. In front, however, it is completed by the upper end of the sternum, with which the medial ends of the clavicles articulate. Behind, the scapulae are separated from each other by a wide gap and are connected to the trunk by muscles only. The *pelvic girdle* is formed by the hip bones, which articulate with each other in front at the pubic symphysis so that the girdle is complete anteriorly. Posteriorly the girdle is incomplete, but the gap is filled by the upper part of the sacrum, with which the hip bones articulate. The pelvic girdle, with the sacrum, forms a complete ring, massive and comparatively rigid, in marked contrast with the lightness and mobility of the shoulder girdle.

THE BONES OF THE UPPER LIMB

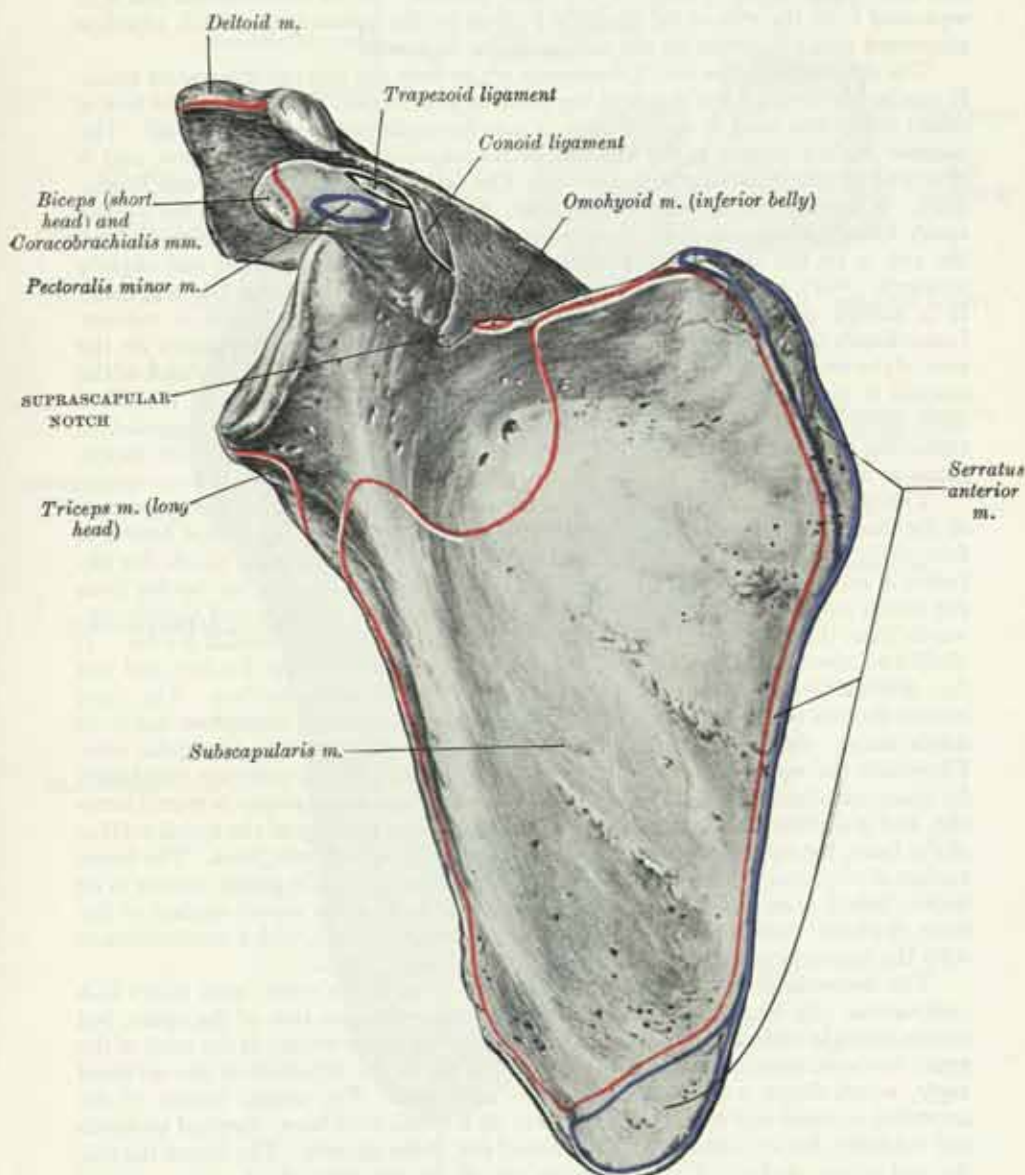
THE SCAPULA (figs. 378, 379, 380)

General features.—The *scapula* is a large, flattened, triangular bone which lies on the posterolateral aspect of the chest wall, covering parts of the second to the seventh ribs. It presents for examination costal and dorsal surfaces, upper, lateral and medial borders, inferior, superior and lateral angles and three bony processes, viz., the spine, its continuation the acromion, and the coracoid process. The *lateral angle* is truncated and bears the glenoid cavity for articulation with the head of the humerus. This part of the bone may be regarded as the head, and it is connected to the plate-like body by an inconspicuous neck. The long axis of the scapula is nearly vertical and the relatively featureless *costal surface* can easily be distinguished from the *dorsal surface*, which is interrupted by the shelf-like projection of the

spine (fig. 380). The bone is very much thickened in the immediate neighbourhood of the lateral border, which runs from the inferior angle *below*, to the glenoid cavity *above*. The student now possesses sufficient information to enable him to assign a given scapula correctly to its appropriate side of the body.

The *costal surface* (fig. 378), which is directed medially and forwards when the arm is by the side, is slightly hollowed out, especially in its upper part. Near the

FIG. 378.—The right scapula. Costal aspect.



lateral border it presents a longitudinal, rounded ridge, stout and salient in the neighbourhood of the neck, but becoming less prominent below, which is separated from the lateral border by a narrow, grooved area. The *dorsal surface* (fig. 379) is divided into a smaller, upper area and a larger, lower area by a shelf-like projection, termed the *spine of the scapula*. These two areas communicate with each other through the *spinoglenoid notch*, which lies between the free, lateral border of the spine and the dorsal aspect of the neck of the bone. A flattened strip, for muscular attachments, marks the dorsal surface along the lateral border.

The *lateral border* of the scapula forms a sharp, roughened ridge,* which runs sinuously from the inferior angle to the glenoid cavity. At its upper end it widens into a rough, somewhat triangular area, which is termed the *infraglenoid tubercle* (fig. 380). Throughout its whole length the lateral border is thickly covered with muscles and cannot be felt satisfactorily in the living subject. The *medial border* of the scapula extends from the inferior to the superior angle. In its lower two-thirds this border can easily be felt through the skin, but its upper third is more deeply placed and cannot be palpated in the normal subject. The *superior border*, thin and sharp, is the shortest of the three borders. At its anterolateral end it is separated from the root of the coracoid process by the *suprascapular notch*, which is converted into a foramen by the suprascapular ligament.

The *inferior angle* lies over the seventh rib, or over the seventh intercostal space. It can be felt through the skin and the muscles which cover it and, when the arm is raised above the head, it can be seen to pass forwards round the chest wall. The *superior angle* is placed at the junction of the superior and medial borders, and is obscured by the muscles which cover it. The *lateral angle* is truncated and broadened. It constitutes the head of the bone. On its free surface it bears the *glenoid cavity* for articulation with the head of the humerus in the shoulder-joint. When the arm is by the side the glenoid cavity faces forwards and laterally and slightly upwards. Very gently hollowed out, it forms a poor socket for the humeral head. It is narrow above and wider below, and is therefore pear-shaped in outline. Immediately above the glenoid cavity a small roughened area encroaches on the root of the coracoid process and is termed the *supraglenoid tubercle*. The *neck* of the scapula is the constriction immediately adjoining the head. It can be identified most easily on its inferior and dorsal aspects. Ventrally, it can be regarded as extending between the infraglenoid tubercle and the anterior margin of the suprascapular notch.

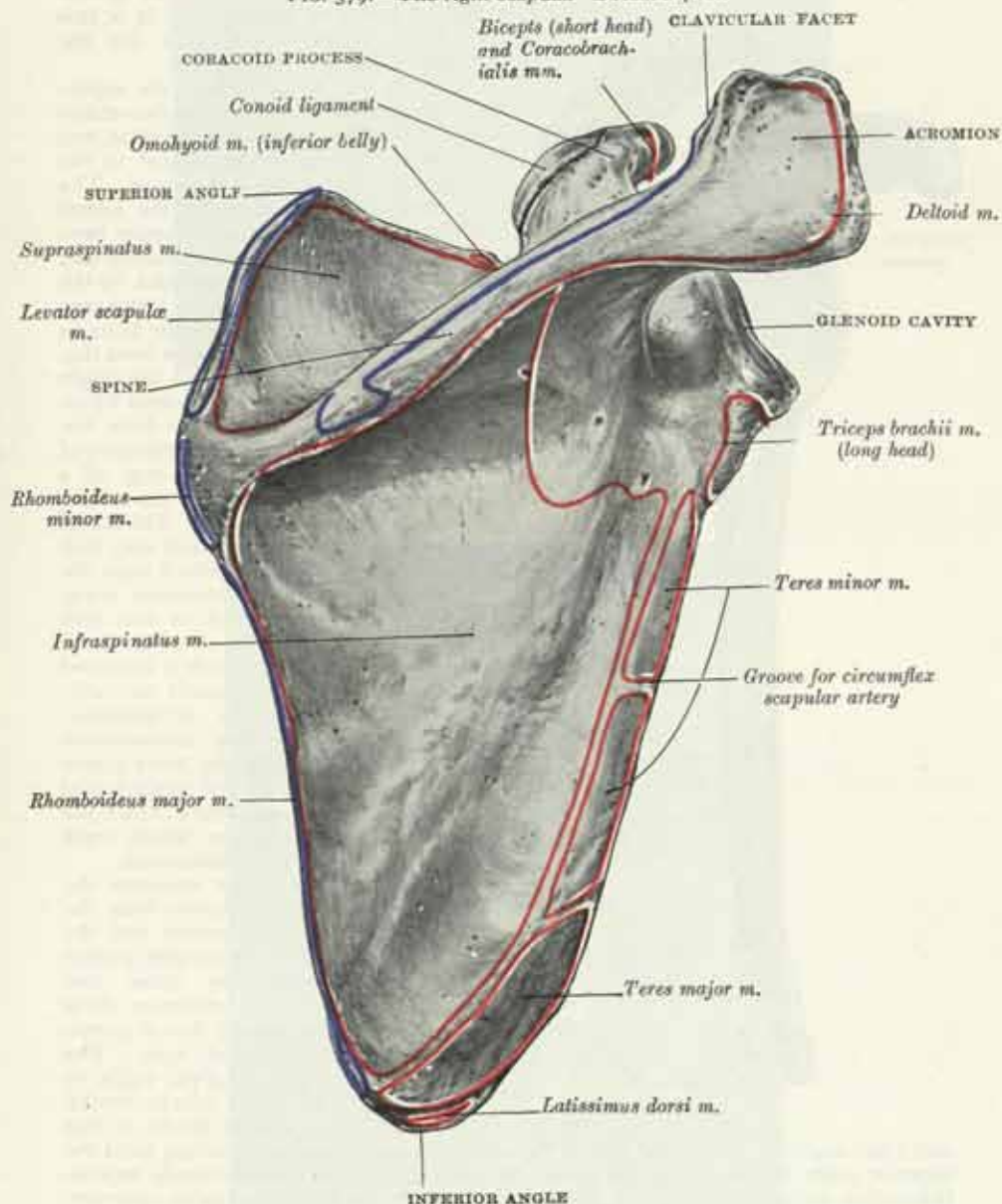
The *spine of the scapula* (fig. 379) forms a shelf-like projection on the upper part of the dorsal surface of the bone, and is triangular in shape. Its lateral border is free, thick and rounded and helps to bound the *spinoglenoid notch*, which lies between it and the dorsal surface of the neck of the bone. Its anterior border joins the dorsal surface of the scapula along a line which runs laterally and slightly upwards from the junction of the upper and middle thirds of the medial border. It should be noted that the plate-like body of the bone is bent along this line, and this fact accounts for the concavity of the upper part of the costal surface. The third border is often termed the *crest of the spine*, and is *subcutaneous throughout nearly its whole extent*. At its medial end the crest expands into a smooth, triangular area. Elsewhere the upper and lower edges and the surface of the crest are roughened for muscular attachments. The upper surface of the spine widens as it is traced laterally, and is slightly hollowed out. Together with the upper area of the dorsal surface of the bone, the upper surface of the spine forms the *supraspinous fossa*. The lower surface is overhung by the crest at its medial, narrow end, but is gently convex in its wider, lateral portion. Together with the lower area of the dorsal surface of the bone, the lower surface of the spine forms the *infraspinous fossa*, which communicates with the supraspinous fossa through the spinoglenoid notch.

The *acromion* projects freely from the lateral end of the spine, with which it is continuous. Its long axis, however, does not coincide with that of the spine, but makes an angle with it of rather more than 90° . The lower border of the crest of the spine becomes continuous with the lateral border of the acromion at the *acromial angle*, which forms a subcutaneous, bony landmark. The medial border of the acromion is short and is marked anteriorly by a small, oval facet, directed upwards and medially, for articulation with the lateral end of the clavicle. The lateral border, tip and upper surface of the acromion can all be felt through the skin without difficulty. The *coracoid process* (fig. 379) springs from the upper border of the head of the scapula and is bent sharply so as to project forwards and slightly laterally. When the arm is by the side, the coracoid process points almost straight forwards and its slightly enlarged tip can be felt through the skin, although it is covered by the anterior fibres of the deltoid muscle. It lies 2.5 cm. below the junction of the lateral fourth

* The lateral border is often described as a thick border, but such a description includes in the border the grooved, lateral part of the costal surface and, frequently, the flattened strip along the lateral part of the dorsal surface. The actual border, however, is clearly defined on the bone as a narrow, roughened ridge (fig. 380).

of the clavicle with the rest of the bone. The supraglenoid tubercle marks the root of the coracoid process where it adjoins the upper part of the glenoid cavity. Another impression is placed on the dorsal aspect of the coracoid process at the point where it changes direction. This gives attachment to the conoid part of the coracoclavicular ligament, which will be mentioned again in connexion with the clavicle.

FIG. 379.—The right scapula. Dorsal aspect.

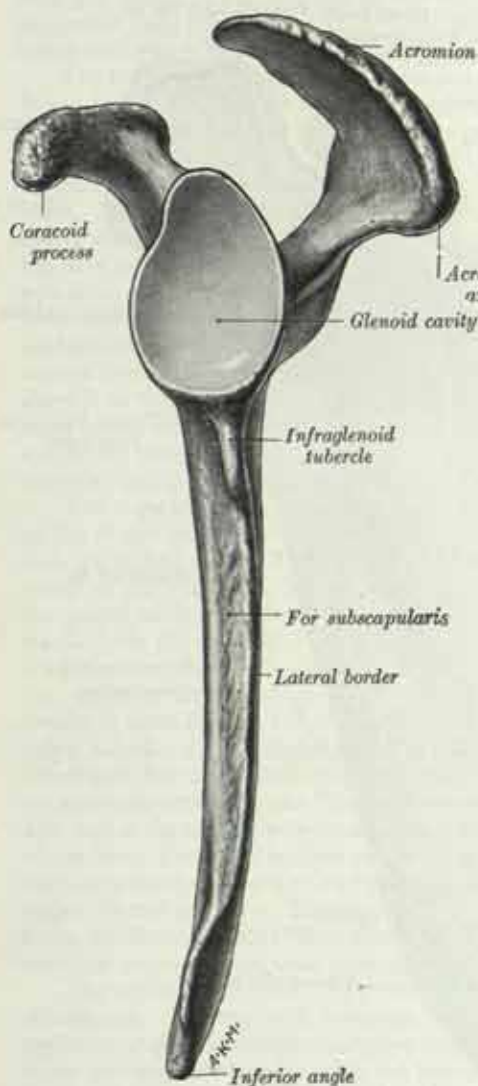


Note.—The insertion of the lower fibres of the Trapezius muscle on the spine is shown but is not labelled.

Particular features.—The *costal surface* gives origin to the subscapularis muscle (fig. 378), which arises from nearly the whole of this aspect including the grooved area immediately adjoining the lateral border and excluding the area adjoining the neck of the bone. Small intramuscular tendons are attached to the roughened ridges which subdivide this surface incompletely into a number of smooth areas. The anterior aspect of the neck is separated from the subscapularis muscle by a bursal protrusion

of the synovial membrane of the shoulder-joint. Near the inferior angle a somewhat oval area gives insertion to the lower five or six digitations of the serratus anterior (fig. 378). The remainder of the muscle is inserted into a narrow strip along the ventral aspect of the medial border, which is wider above, where it receives the large first digitation. The rounded, longitudinal ridge near the lateral border corresponds to a localised thickening of the bone and provides a lever of the necessary strength to enable the serratus anterior to rotate the scapula forwards. In this movement the

FIG. 380.—The left scapula. Lateral aspect.



upper limb is raised from the side and carried above the head against the action of gravity, and it is this latter factor which calls for the provision of a strong lever.

On the *dorsal surface*, the supraspinous fossa in its medial two-thirds gives origin to the supraspinatus, and its margins give attachment to the fascia which covers the muscle. The flattened strip adjoining the lateral border gives origin, in its upper two-thirds, to the teres minor muscle and is grooved, near its upper end, by the circumflex scapular vessels, which pass between the muscle and the bone as they enter the infra-spinous fossa (fig. 379). The lower limit of the origin of the teres minor is indicated by an oblique ridge, which runs from the lateral border to the neighbourhood of the inferior angle and cuts off a somewhat oval area for the origin of the teres major muscle. The dorsal aspect of the inferior angle may give origin to a small slip which joins the deep surface of the latissimus dorsi. With the exception of an area near the neck of the bone, the rest of the infraspinous fossa, which is hollowed out laterally but is convex medially, gives origin to the infraspinatus muscle. The strong infraspinatus fascia passes on to the teres minor and the teres major and sends fascial partitions between them to reach the bone along the ridges which mark the limits of their attachments.

The *lateral border* separates the origin of the subscapularis from the origins of the teres minor and the teres major. These muscles project laterally beyond the bone, and together with the latissimus dorsi cover it so completely that it cannot be felt through the skin. The infraglenoid tubercle gives origin to the long head of the triceps brachii muscle. The *medial border* is thin

and often angled opposite the root of the spine. A narrow strip, extending from the superior angle to the root of the spine, gives insertion to the levator scapulae muscle. Below this, and opposite the root of the spine, the rhomboideus minor gains insertion. The remainder of the border provides insertion for the rhomboideus major (p. 614).

The *upper border* of the scapula is thin and sharp. Near the suprascapular notch it gives origin to the inferior belly of the omohyoid muscle, and the posterior limit of the notch gives attachment to the suprascapular ligament, which is sometimes ossified. The foramen completed by the ligament transmits the suprascapular nerve to the supraspinous fossa, whereas the suprascapular vessels pass backwards above the ligament.

The *inferior angle* of the scapula is covered on its dorsal aspect by the upper border of the latissimus dorsi muscle, which frequently receives a small slip of origin from this part of the bone. The *superior angle* of the scapula is covered by the upper part of

PLATE IX



FIG. 1.—Radiograph of the elbow of a child, aged 10 years. Lateral view. The upper epiphysis of the radius, the olecranon epiphysis and the centre for the capitulum and the lateral part of the trochlea can be recognised without difficulty.



FIG. 2.—Radiograph of an adult hand.



FIG. 1.—Radiograph of the hand and wrist of a child, aged 2½ years. The capitate and hamate bones are in process of ossification, but the other carpal bones are still cartilaginous. The centre for the head of the ulna has not yet appeared, but the centre for the lower epiphysis of the radius is present. Note the condition of the metacarpal bones and phalanges.

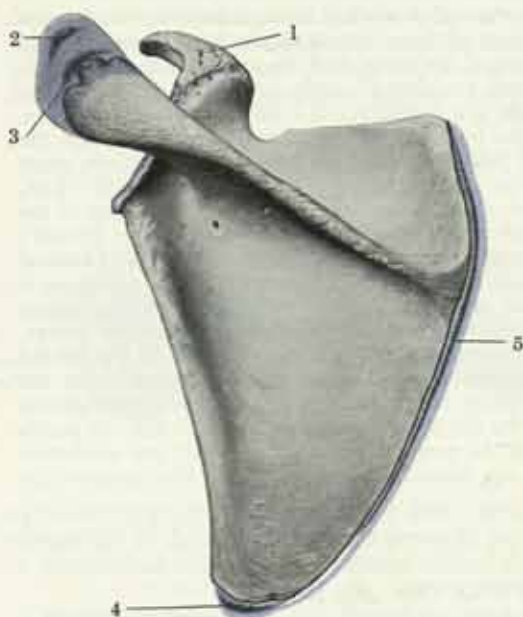


FIG. 2.—Radiograph of hand and wrist of a child, aged 11 years. All the centres of ossification are present except that for the pisiform bone. Note how the first metacarpal differs from the other metacarpal bones.

the trapezius muscle. The truncated *lateral angle* bears the *glenoid cavity*, the margins of which give attachment to the glenoidal labrum. The surface of the cavity is covered with a layer of hyaline articular cartilage, which is thinnest at the centre and thickest at the periphery. Its anterior margin gives attachment to the glenohumeral ligaments (p. 484). When the arm is by the side the cavity is directed forwards, laterally and slightly upwards. When the arm is raised above the head it is directed almost straight upwards.

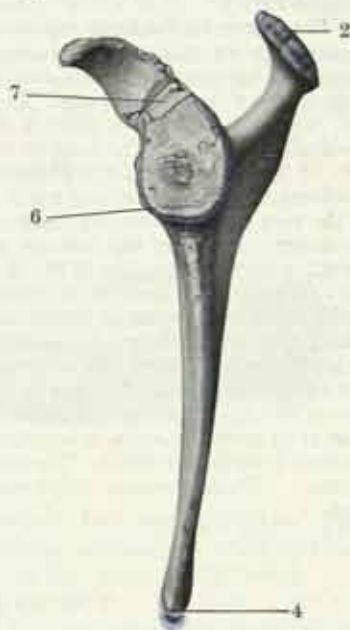
The *spine of the scapula* gives attachment by its upper and lower surfaces to the supra- and infraspinatus muscles, respectively. The flattened, triangular area at its root lies opposite the spine of the third thoracic vertebra and is covered by the tendon of the trapezius, a bursa intervening to enable the tendon to play over this part of the bone. The lower border of the crest gives origin to the posterior fibres of the deltoid muscle, which often produce an elongated tubercle in this situation. The

FIG. 381A.—A plan of the ossification of the scapula.



A—1. Coracoid centre, appears 1st year; joins \bar{c} 15th year. 2. Distal acromion centre appears 16th year. 3. Proximal acromion centre appears 14th or 15th year. 4. Centre for inferior angle appears 15th year; joins 20th–25th year. 5. Centre for medial border appears 17th year; joins 17th–22nd year.

FIG. 381B.—The lateral aspect of the left scapula, showing secondary centres of ossification. Semi-diagrammatic.



B—2. Distal acromion centre, appears 16th year. 4. Centre for inferior angle appears \bar{c} 15th; joins 20th–25th year. 6. Centre for rim of glenoid cavity. 7. Subcoracoid centre, which is very variable in its size.

upper border of the crest receives the insertion of the lower fibres of the trapezius, which often encroach on the dorsal or subcutaneous aspect of the crest, especially near the root of the spine.

The *acromion* is subcutaneous over its dorsal surface, being covered only by the skin and superficial fascia. The lateral border, which is thick and irregular, and the tip of the process, as far round as the clavicular facet, give origin to the middle fibres of the deltoid muscle. The medial aspect of the tip gives attachment, below the deltoid, to the lateral end of the coraco-acromial ligament. The articular capsule of the acromio-clavicular joint is attached around the margins of the clavicular facet. Behind the facet, the medial border of the acromion gives insertion to the horizontal fibres of the trapezius muscle. The inferior aspect of the acromion is relatively smooth, and together with the coraco-acromial ligament and the coracoid process forms a protective arch over the shoulder-joint. The tendon of the supraspinatus passes below the overhanging acromion and is separated from it and from the deltoid muscle by the subacromial bursa.

The *coracoid process* lies below the clavicle at the junction of the lateral fourth with

the rest of the bone and is connected to its under surface by the coraco-clavicular ligament. The attachment of the conoid part of the ligament has already been considered (p. 359): the trapezoid part is attached to the upper aspect of the horizontal part of the process (fig. 378). The superior aspect of the process receives also the insertion of the pectoralis minor muscle. Its lateral border gives attachment to the wider, medial end of the coraco-acromial ligament and, below that, to the coraco-humeral ligament. The enlarged tip of the process gives origin to the coracobrachialis, medially, and to the short head of the biceps, laterally. It is covered in life, by the anterior fibres of the deltoid muscle and can be identified only on deep pressure through the lateral border of the infraclavicular fossa. The inferior aspect of the process is smooth and helps to complete the coraco-acromial arch.

Structure.—The head, processes, and thickened parts of the scapula contain spongy substance; the rest consists of a thin layer of compact bone. The central part of the supraspinous fossa and the greater part of the infraspinous fossa are thin; occasionally the bone is wanting in these situations, the gaps being filled by fibrous tissue.

Ossification (fig. 381).—The scapula is ossified from eight or more centres: one for the body, two for the coracoid process, two for the acromion, one for the medial border, one for the inferior angle and one for the lower part of the rim of the glenoid cavity.

The centre for the body appears in the eighth week of intrauterine life, and spreads to form an irregular quadrilateral plate of bone, immediately behind the glenoid cavity. This plate forms the chief part of the bone, and the spine grows backwards from it about the third month. At birth, the glenoid cavity, coracoid process, acromion, medial border, and inferior angle are cartilaginous. In the first year of life, ossification begins in the middle of the coracoid process, and this process joins the rest of the bone about the fifteenth year. Between the tenth and twentieth years ossification of the remaining parts takes place, usually in the following order: first, in the root of the coracoid process (subcoracoid centre); second, near the base of the acromion; third, in the inferior angle and contiguous part of the medial border; fourth, near the extremity of the acromion; fifth, in the medial border. The base of the acromion is formed by an extension from the spine; the rest of the acromion is ossified from two centres which unite, and then join the extension from the spine. The upper one-third of the glenoid cavity is ossified from the subcoracoid centre, which appears between the tenth and eleventh, and joins between the sixteenth and the eighteenth years. Further, a horseshoe-shaped epiphyseal plate appears for the rim of the lower part of the glenoid cavity about puberty; thicker at its peripheral than at its central margin, it converts the flat glenoid cavity of the child into the gently concave fossa of the adult. The tip of the coracoid process frequently has a separate centre. These various epiphyses are joined to the bone by the twenty-fifth year.

THE CLAVICLE (figs. 382, 383)

General features.—The clavicle lies almost horizontally at the root of the neck and is *subcutaneous throughout its whole extent*. Its most important functions are: (1) to act as a prop which braces back the shoulder and enables the limb to swing clear of the trunk: and (2) to transmit a part of the weight of the limb to the axial skeleton, in this way diminishing the muscular effort required for that purpose. The lateral or *acromial end* of the bone is flattened and articulates with the medial side of the acromion, whereas the medial or *sternal end* is enlarged and articulates with the clavicular notch of the manubrium sterni. The *shaft* is gently curved and in shape resembles the italic letter *f*, being convex *forwards* in its medial portion and concave forwards in its lateral portion. The *inferior* aspect of the intermediate third is grooved in its long axis. The student is now in a position to refer a given clavicle correctly to its appropriate side of the body.

The **lateral one-third** of the clavicle is flattened and has a superior and an inferior surface, limited by an anterior and a posterior border. The *anterior border* is concave, thin and roughened and may be marked by a small tubercle, termed the *deltoid tubercle*. The *posterior border*, also roughened for muscular attachments, is convex backwards. The *superior surface* is roughened near its margins but is smooth centrally, where it can be felt through the skin. The *lower surface* presents two obvious markings. Close to the posterior border, at the junction of the lateral one-fourth with the rest of the bone, a prominent tubercle gives attachment to the conoid part of the coracoclavicular ligament and is termed the *conoid tubercle*. From the lateral side of this tubercle a narrow, roughened strip runs forwards

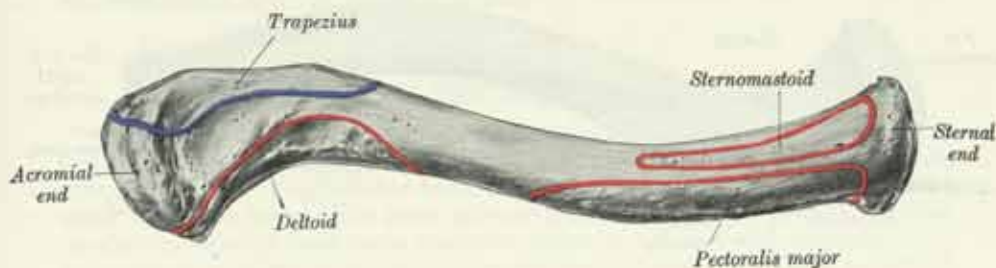
and laterally, reaching almost as far as the acromial end (fig. 383). It is termed the *trapezoid line* and gives attachment to the trapezoid ligament.

The **medial two-thirds** of the shaft of the clavicle, which is cylindrical or prismoid in form, usually possess four surfaces, but the inferior surface is often reduced to a mere ridge. The *anterior surface* is roughened over most of its extent but it is smooth and rounded at its lateral end, where it forms the upper boundary of the infravicular fossa (p. 616). The *upper surface*, also, is roughened in its medial part and smooth at its lateral end. The *posterior surface* is smooth and featureless. The *inferior surface* is marked, near the sternal end, by a roughened impression, which is often depressed below the surface. This gives attachment to the costo-clavicular ligament, which connects the clavicle to the upper surface of the first rib and its cartilage and helps to limit its range of movement. The lateral half of this surface shows a groove in the long axis of the bone.

The flattened *acromial end* of the clavicle presents a small oval articular facet, which articulates with the medial aspect of the acromion at the acromioclavicular joint. The facet faces laterally and slightly downwards.

The *sternal end* of the clavicle is directed medially, and a little downwards and forwards, to articulate with the clavicular notch of the manubrium sterni. The sternal surface is quadrangular (sometimes triangular) in form, and its uppermost part is slightly roughened for ligamentous attachments. Elsewhere, in a normal bone, the surface is smooth and articular and it is carried round on to the inferior

FIG. 382.—The right clavicle. Viewed from above.



surface for a short distance, where it articulates with the first costal cartilage. The sternal end of the clavicle projects upwards beyond the manubrium sterni and can be felt without difficulty in the lateral wall of the jugular (suprasternal) fossa.

Particular features.—The *lateral one-third* of the shaft gives attachment to the deltoid muscle by its anterior border and to the trapezius muscle by its posterior border. Both muscles encroach on the upper surface. The coracoclavicular ligament attached to the conoid tubercle and the trapezoid line (fig. 383), transmits a large part of the weight of the upper limb to the clavicle. This weight is counteracted by the tonus of the trapezius muscle, which supports the lateral part of the bone. From the conoid tubercle the weight is transmitted through the medial two-thirds of the shaft to reach the axial skeleton. Fracture of the clavicle medial to the conoid tubercle interrupts the line of weight transmission, so that practically the whole weight of the limb has to be supported by the trapezius. The muscle is unable to meet the demand and the limb therefore drops on the affected side.

The *medial two-thirds* give attachment anteriorly to the clavicular head of the pectoralis major muscle, and, as a rule, the area is clearly indicated on the bone. The clavicular head of the sternomastoid arises from the medial half of the upper surface, but the marking on the bone is not very conspicuous. The smooth, posterior surface is devoid of muscular attachments except at its lower part immediately adjoining the sternal end, where the lateral fibres of the sternohyoid arise. Medially, this surface is related to the lower end of the internal jugular vein (from which it is separated by the sternohyoid muscle), the termination of the subclavian vein and the commencement of the brachiocephalic (innominate) vein. More laterally, it arches in front of the trunks of the brachial plexus and the third part of the subclavian artery. The supra-scapular vessels are related to the upper part of this surface. The *inferior surface* gives insertion to the subclavius muscle in the subclavian groove (fig. 383), and the edges of the groove give attachment to the clavipectoral fascia, which encloses the muscle. The posterior lip of the groove runs into the conoid tubercle and carries

the fascia into continuity with the conoid ligament. A nutrient foramen is found in the lateral end of the groove, running in a lateral direction. The nutrient artery concerned is derived from the suprascapular artery. The impression for the costo-clavicular ligament is very variable in its character.

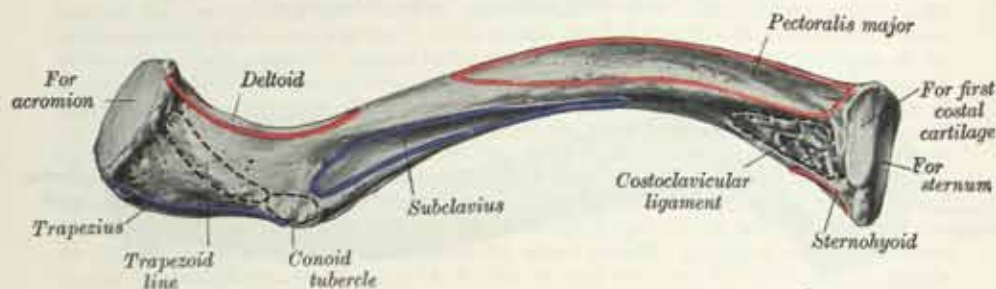
The margins of the articular facet at the *acromial end* give attachment to the articular capsule of the acromioclavicular joint.

The roughened, upper part of the *sternal end* provides attachment for the inter-clavicular ligament, the articular capsule and the articular disc of the sternoclavicular joint. The sternal surface, denuded of its articular cartilage, is rarely smooth and is usually irregular and somewhat pitted.

In a woman, the clavicle is shorter, thinner, less curved and smoother than in a man. In women the acromial end is a little below the level of the sternal end; in men it is on a level with, or slightly higher than, the sternal end. In those who perform hard manual labour the clavicle is thicker and more curved, and its ridges for muscular attachment are better marked.

Structure.—The clavicle consists of spongy substance, enveloped by a layer of compact bone which is much thicker in the intermediate part of the bone than at the ends. *Unlike other long bones it does not possess a medullary cavity.*

FIG. 383.—The right clavicle. Viewed from below.



Ossification.—The clavicle begins to ossify before any other bone in the body, and is ossified from three centres. The shaft of the bone is ossified in membrane from two primary centres *—a medial and a lateral—which appear between the fifth and sixth weeks of intrauterine life, and fuse about the forty-fifth day; a secondary centre for the sternal end appears about the eighteenth or twentieth year, and unites with the body of the bone about the twenty-fifth year. A secondary centre sometimes develops in the cartilage at the acromial end at about eighteen to twenty. The epiphysis so formed is always small and rudimentary and rapidly joins the rest of the bone.†

In a 14 mm. embryo the future clavicle is represented by a band of mesenchyme which extends from the acromion of the scapula to the tip of the first rib, and is continuous with the rudiment of the sternum. In this band a medial and a lateral mass of 'precartilage' is developed, and in the mesenchyme intervening between them the two centres for the body of the bone appear and soon fuse with each other. The sternal and acromial parts of the precartilaginous masses are converted into cartilage, and into this the ossification of the body of the bone extends.

The primitive reptilian shoulder girdle comprises a dorsal element—the scapula—and two ventral elements, of which the anterior (headward) is the precoracoid and the posterior (caudal) is the coracoid. The primitive girdle of the hind limb also possesses three elements, of which the ilium is homologous with the scapula, the pubis with the precoracoid and the ischium with the coracoid. The clavicle, which is a membrane bone and therefore morphologically distinct from the others, is an additional element in the shoulder girdle but is not represented in the pelvic girdle. It is doubtful whether any trace of the precoracoid persists in the human skeleton, although the presence of two primary centres for the clavicle is regarded by many authorities as an

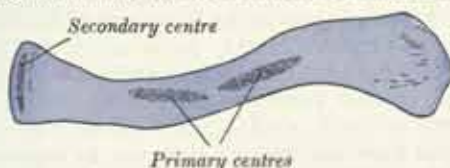
* F. P. Mall, *Am. J. Anat.*, 5, 1906; E. Fawcett, *J. Anat., Physiol.*, 47, 1913; Hanson, *Anat. Rec.*, 19, 1920.

† T. Wingate Todd and J. D'Erice, jr., *Am. J. Anat.*, 41, 1928.

indication that the human clavicle corresponds both to the precoracoid and to the clavicle in the reptilian shoulder-girdle. Other authorities believe that the first coracoid centre to appear in man represents the precoracoid element, while the subcoracoid centre is regarded as representing the caudal ventral element in the reptilian girdle.

The clavicle is absent in animals in which the forelimbs are used principally or entirely for progression, e.g. the ungulates and carnivores, but it is present and well developed in animals which use the limb for prehension, e.g. many rodents, the primates and man.

FIG. 384.—Diagram showing the three centres of ossification of the clavicle.



Applied Anatomy.—The clavicle is very frequently fractured. The most common cause is indirect violence, as the result of force applied to the hand or shoulder, and the bone then gives way at the junction of its lateral with its intermediate third, that is to say, at the junction of the two curves, for this is its weakest part. The consequent deformity is caused by the weight of the arm, which acts on the lateral fragment through the coraco-clavicular ligament and draws it downwards. The medial fragment, as a rule, is little displaced.

THE HUMERUS (figs. 385-392)

General features.—The humerus is the longest and largest bone of the upper limb. It comprises expanded upper and lower extremities and a more or less cylindrical shaft. The rounded head occupies the upper and medial part of the upper end of the bone. The lesser tubercle (tuberosity) projects from the front of the shaft, close to the head, and is limited on its lateral side by a well-marked groove. By examination of the head and the lesser tubercle the student should be able to assign a given humerus correctly to its appropriate side of the body.

The **upper end** of the humerus consists of the head, and the greater and lesser tubercles.

The *head* of the humerus (figs. 385, 387) forms rather less than half a sphere, and its smooth surface is covered with hyaline articular cartilage in life and in the unmacerated specimen. When the arm is at rest by the side, it is directed medially, backwards and upwards to articulate with the glenoid cavity of the scapula. The humeral articular surface is much more extensive than the glenoid cavity, and only a portion of it is in contact with the cavity in any one position of the arm. The margin of the head is most distinct in its medial part.

The *anatomical neck* of the humerus immediately adjoins the margin of the head and forms a slight constriction, which is least apparent in the neighbourhood of the tubercle.

The *lesser tubercle* is placed on the anterior aspect of the bone immediately beyond the anatomical neck, and shows a smooth, muscular impression on its upper part. Although thickly covered by muscle it can be felt on deep pressure through the skin, 3 cm. below the tip of the acromion. The bony prominence slips away from the examining finger when the humerus is rotated. The lateral edge of the lesser tubercle is sharp and forms the medial border of the intertubercular sulcus (bicipital groove).

The *greater tubercle* occupies the lateral part of the upper end of the humerus and is the *most lateral bony point in the shoulder region*. It projects beyond the lateral border of the acromion and, covered by the thick, fleshy deltoid muscle, is responsible for the normal rounded contour of the shoulder. The portion of the tubercle which adjoins the anatomical neck shows three flattened impressions for muscular attachments.

The *intertubercular sulcus* separates the two tubercles and lodges the tendon of the long head of the biceps muscle.

The **shaft** of the humerus is almost cylindrical in its upper half but is triangular on section in its lower half, which is compressed in an anteroposterior direction. It can be identified when the arm is grasped firmly, but its outline is obscured by the strong muscles which clothe it. It presents three surfaces and three borders—which are not everywhere equally obvious.

The *anterior border* commences above on the front of the greater tubercle and runs downwards almost to the lower end of the bone. Its upper third forms the lateral lip of the intertubercular sulcus and is roughened for muscular attachments. The succeeding portion is also roughened and forms the anterior limit of the deltoid tuberosity, but the lower half of the border is smooth and rounded.

The *lateral border* is conspicuous at the lower end of the bone, where its sharp edge is roughened along its anterior aspect. In its middle and upper thirds the border is barely discernible to the inexperienced eye, but in a well-marked bone it can be traced upwards to the posterior surface of the greater tubercle. About its middle the border is interrupted by a wide, shallow groove which crosses the bone obliquely, passing downwards and forwards from its posterior to its anterior surface. It is termed the *sulcus for the radial nerve*.

The *medial border*, although rounded, can be identified without difficulty in the lower half of the shaft. A little below the middle of the bone it presents a roughened strip, and superiorly it becomes indistinct until it reappears as the medial lip of the intertubercular sulcus. In this situation the border is again roughened and can be traced into the lesser tubercle.

The *anterolateral surface* of the humerus lies between the anterior and the lateral borders. A little above its middle it is marked by a V-shaped roughened area which is termed the *deltoid tuberosity*. The limbs of the V are broad and behind the posterior limb the groove for the radial nerve runs downwards and fades away on the lower part of the surface.

The *anterior surface* is bounded by the anterior and the medial borders of the bone. Rather less than its upper third forms the rough floor of the intertubercular sulcus, but the rest of the surface is smooth. A little below its middle the nutrient foramen, which is directed downwards, opens close to the medial border.

The *posterior surface* lies between the medial and the lateral borders and is the most extensive surface of the three. Its upper third is crossed by a faint ridge, sometimes roughened, which runs obliquely downwards and laterally. The middle third is crossed by the commencement of the groove for the radial nerve. Rather more than the lower third forms an extensive, flattened surface, which widens considerably below.

The **lower end** of the humerus (figs. 385, 387, 389), which constitutes the **condyle**, is expanded transversely, and presents articular and non-articular portions.

The *articular portion* takes part with the radius and the ulna in the formation of the elbow-joint. It is divided by a faint groove into a lateral, convex surface, termed the *capitulum*, and a medial, pulley-shaped surface, termed the *trochlea*.

The *capitulum* is a rounded, convex projection, considerably less than half a sphere, which covers the anterior and inferior surfaces of the lateral part of the condyle of the humerus but does not extend on to its posterior surface. It articulates with the disc-like head of the radius, which lies in contact with its inferior surface in full extension of the elbow but moves on to its anterior surface when the joint is flexed.

The *trochlea* is a pulley-shaped surface, which covers the anterior, inferior and posterior surfaces of the condyle of the humerus. On its lateral side it is separated from the capitulum by a faint groove, but its medial margin is salient and projects downwards beyond the rest of the bone. The trochlea articulates with the trochlear notch of the ulna. When the elbow is extended the inferior and posterior aspects of the trochlea are in contact with the ulna, but, as the joint is flexed, the trochlear notch rolls forwards on to the anterior aspect and the posterior aspect is then left uncovered. The downward projection of the medial edge of the trochlea is the principal factor in determining the angulation which is present between the long axis of the humerus and the long axis of the supinated forearm when the elbow is extended. The angle, which is of approximately 170° , is open to the lateral side and is termed the 'carrying angle' (p. 493). Owing to the existence of this angulation,

FIG. 385.—The left humerus. Anterior aspect.

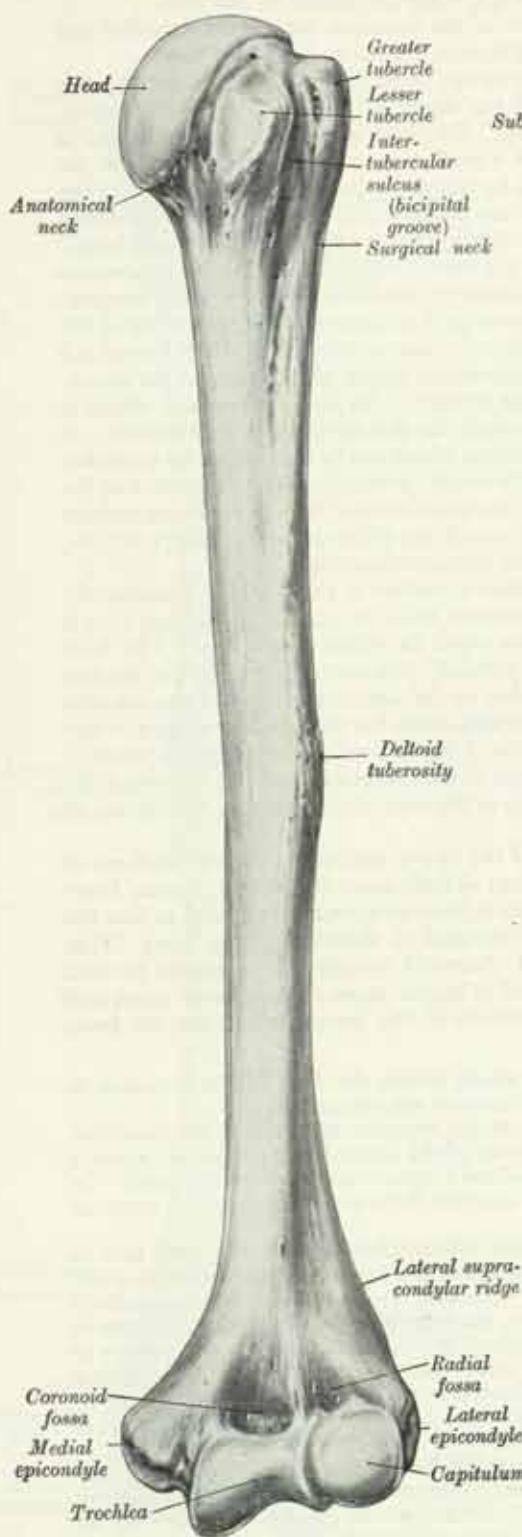
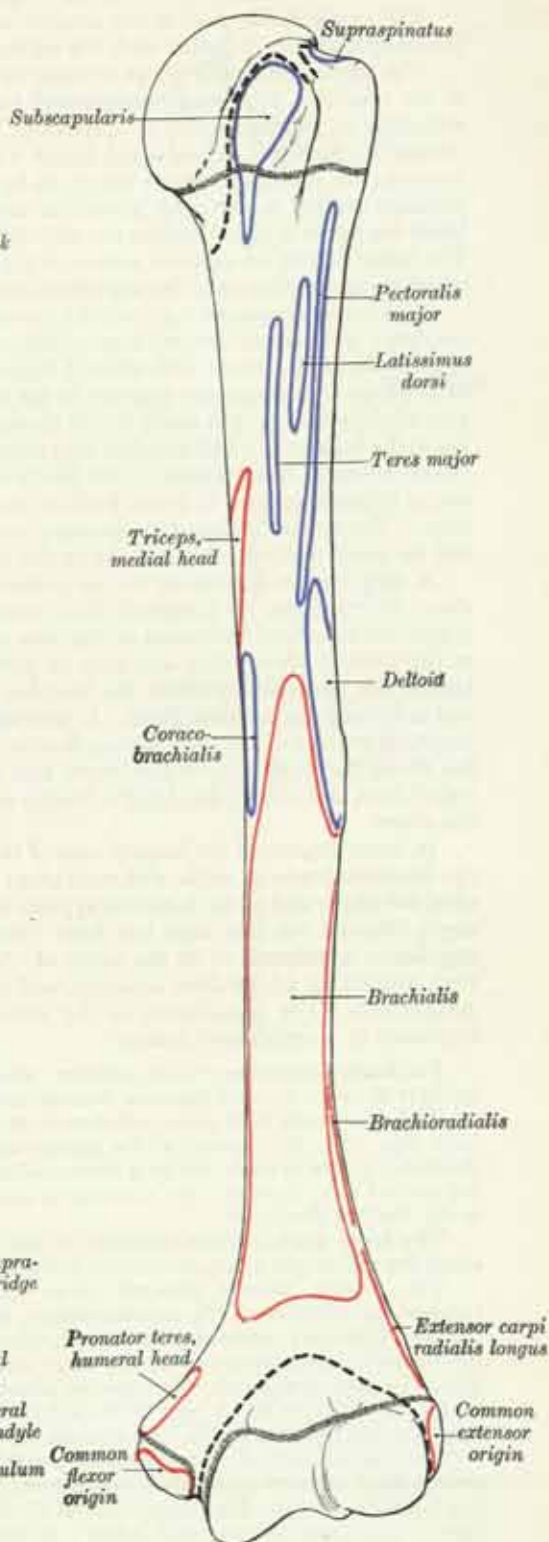


FIG. 386.—Key to fig. 385.



The interrupted lines indicate the attachment of the capsular ligaments; the stippled lines mark the position of the epiphyseal lines.

the ulnar border of the supinated and extended forearm cannot be brought into contact with the lateral surface of the thigh, when the arm is by the side.

The *non-articular part* of the condyle of the humerus includes the medial and lateral epicondyles together with the olecranon, coronoid and radial fossæ.

The *medial epicondyle* forms a conspicuous, blunt projection on the medial side of the condyle. It is subcutaneous and can easily be identified through the skin, especially in passive flexion of the elbow. Its posterior surface is smooth and is crossed by the ulnar nerve, which lies in a shallow sulcus, as it runs down into the forearm. In this situation the nerve can be felt and rolled against the bone. If the pressure exerted is sufficient, sensations are aroused identical with those produced when the nerve is jarred against the epicondyle, i.e. by a knock on the 'funny bone'. The lower part of the anterior surface of the medial epicondyle shows an impression which gives attachment to the superficial group of the flexor muscles of the forearm.

The *lateral epicondyle* occupies the lateral part of the non-articular portion of the condyle; but does not project beyond the lateral supracondylar ridge. Its lateral and anterior surfaces show a well-marked impression, which gives origin to the superficial group of the extensor muscles of the forearm. Its posterior surface, which is very slightly convex, can easily be felt through the skin at the back of the elbow. It lies at the bottom of a well-marked depression, which can be seen when the extended elbow is viewed from behind. The lateral border of the humerus terminates at the lateral epicondyle, and its lower portion is usually termed the *lateral supracondylar ridge*. The medial border of the humerus terminates below at the medial epicondyle, and its lower portion is termed the *medial supracondylar ridge*.

A deep hollow is situated on the posterior surface of the condyle, immediately above the trochlea. It is termed the *olecranon fossa*, on account of the fact that it lodges the tip of the olecranon of the ulna when the elbow is extended. The floor of the fossa is always thin and may be partially deficient. A similar but smaller hollow lies immediately above the trochlea on the anterior surface of the condyle and is termed the *coronoid fossa*. It provides room for the anterior margin of the coronoid process of the ulna during flexion of the elbow. A very slight depression lies above the capitulum on the lateral side of the coronoid fossa. It is termed the *radial fossa*, since it is related to the margin of the head of the radius in full flexion of the elbow.

In lower mammals the longest axes of the upper and lower articular surfaces of the humerus make an angle with each other of little more than 90° . In man, however, the upper end of the humerus appears to have been rotated laterally, so that the angle between the two axes has been increased to about 164° (fig. 390). This angulation is referred to as the angle of 'humeral torsion.' It is greater in men than women, in adults than children, and in higher races than in lower races and anthropoids. The significance of the torsion of the humerus has not yet been explained in a satisfactory manner.

Particular features.—The cartilage which covers the *head* of the humerus is thickest at its centre and becomes thinner towards the circumference.

The *anatomical neck* gives attachment to the capsular ligament of the shoulder-joint (figs. 386, 388), except at the upper end of the intertubercular sulcus, where a deficiency exists to allow the long tendon of the biceps to emerge from the joint. On the medial side, however, the attachment extends downwards for 1 cm. or more on to the shaft of the bone.

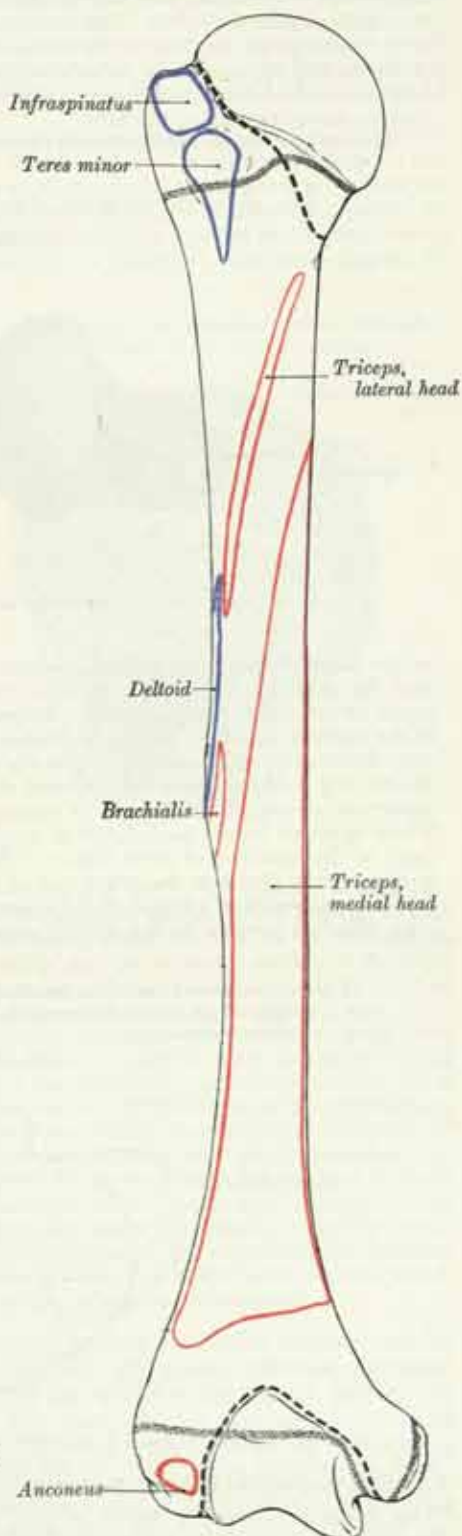
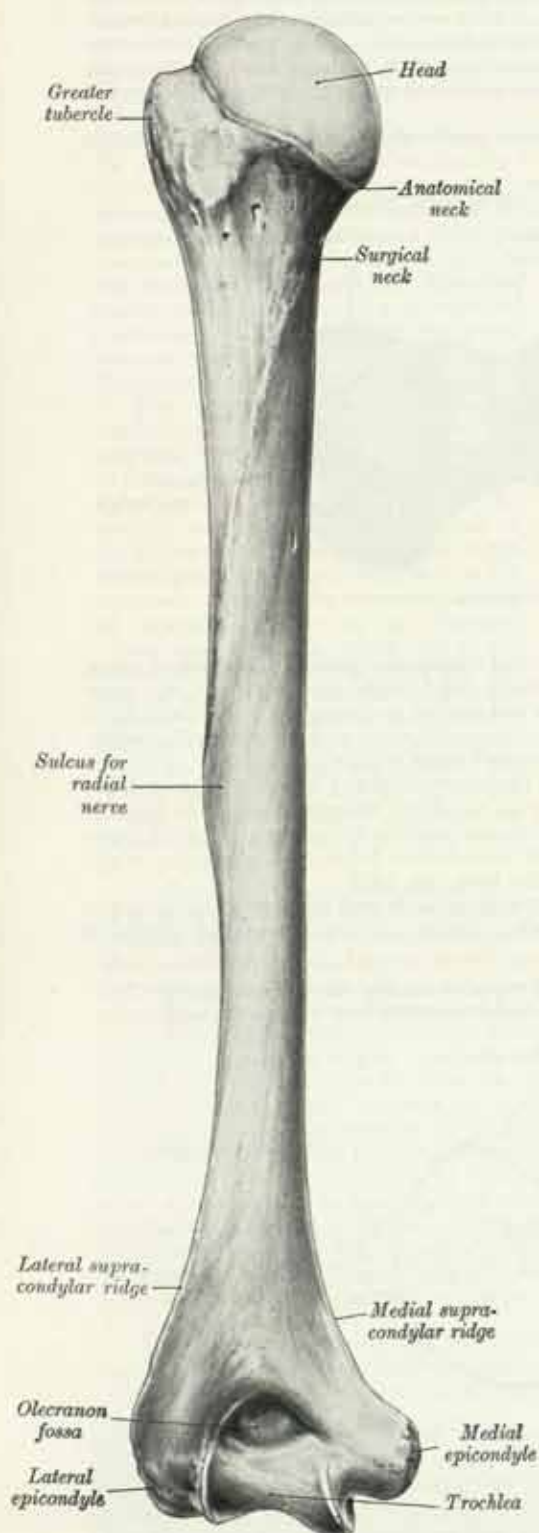
The *lesser tubercle* gives insertion to the subscapularis muscle (fig. 386) and its sharp lateral margin gives attachment to the transverse ligament of the shoulder-joint.

The *greater tubercle* presents three muscular impressions. The uppermost receives the insertion of the supraspinatus; the middle impression gives insertion to the infraspinatus; while the lowermost, which is placed on the posterior surface of the tubercle, gives insertion to the teres minor muscle (fig. 388). The projecting lateral surface of the tubercle presents numerous vascular foramina and is covered by the deltoid muscle. A part of the subacromial bursa may cover the upper part of this area and separate it from the muscle.

The intertubercular sulcus (*bicipital groove*) lodges the long tendon of the biceps, its accompanying synovial sheath, and an ascending branch from the anterior circumflex humeral artery. The rough, lateral lip of the groove gives insertion to the bilaminar tendon of the pectoralis major; its floor receives the tendon of the latissimus dorsi; and its medial lip, the tendon of the teres major. The insertion of the pectoralis major extends to a lower level than the insertion of the teres major, while the insertion of the latissimus dorsi is the least extensive of the three. Below the inter-

FIG. 387.—The left humerus. Posterior aspect.

FIG. 388.—Key to fig. 387.

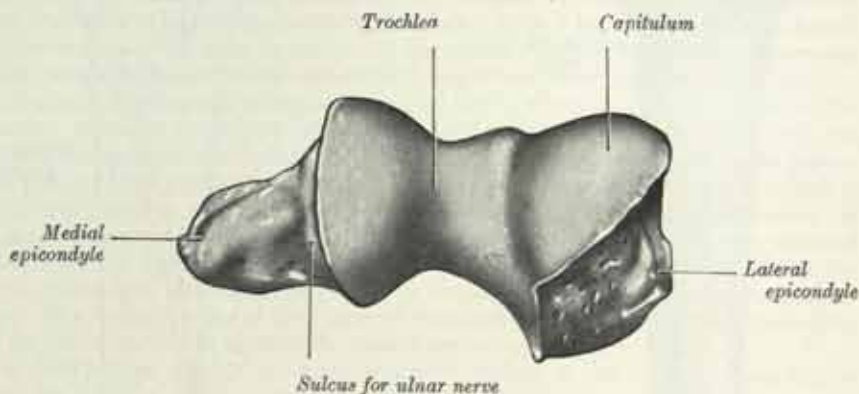


The interrupted lines indicate the attachment of the capsular ligaments; the stippled lines mark the position of the epiphysal lines.

tubercular sulcus the anteromedial surface of the humerus is devoid of muscular attachment over a small area, but its lower half gives origin to the medial portion of the brachialis muscle (fig. 386). The roughened strip on the middle of the medial border of the bone gives insertion to the coracobrachialis muscle. Close to the lowest part of the medial supracondylar ridge this surface gives origin over a narrow area to the humeral head of the pronator teres; and the ridge itself gives attachment to the medial intermuscular septum of the arm.

The oblique ridge which crosses the upper part of the *posterior surface* gives origin

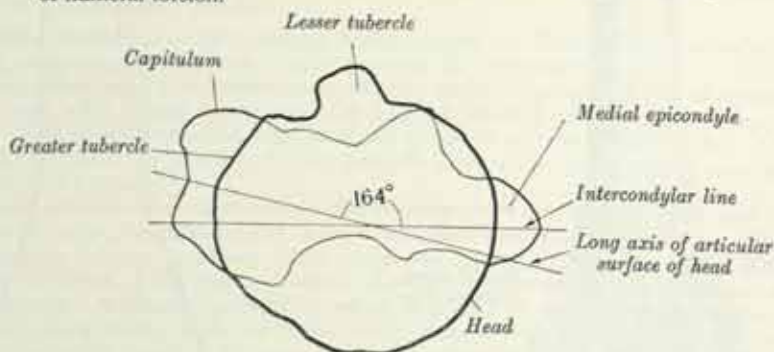
FIG. 389.—The lower end of the left humerus, viewed from below.



to the lateral head of the triceps. Above this muscle the axillary (circumflex) nerve and the posterior circumflex humeral vessels wind round this aspect of the bone under cover of the deltoid muscle. Below and medial to the origin of the lateral head of the triceps, a shallow groove, containing the radial nerve and the profunda vessels, runs downwards and laterally to gain the anterolateral surface of the shaft. The area for the origin of the fleshy medial head of the triceps includes a very large part of the posterior surface of the bone. It covers an elongated triangular area, the apex of which is placed on the medial part of the posterior surface above the level of the lower limit of the insertion of *teres major*. The area widens below and covers the whole surface almost down to the lower end of the bone (fig. 388).

The *anterolateral surface* of the humerus is smooth and featureless in its upper part, which is covered by the deltoid muscle. About, or a little above, the middle of

FIG. 390.—An outline of the head of the left humerus, viewed from above, projected on to the outline of the lower end of the bone to show the angle of humeral torsion.



this surface the deltoid muscle is inserted into the deltoid tuberosity, and below that level the surface gives origin to the lateral fibres of the brachialis, which extend upwards into the floor of the lower end of the groove for the radial nerve (fig. 388). The roughened anterior aspect of the lateral supracondylar ridge gives origin by its upper two-thirds to the brachioradialis and by its lower third to the extensor carpi radialis longus. Behind these muscles the ridge gives attachment to the lateral intermuscular septum of the arm.

The *articular portion of the condyle* of the humerus is curved forwards, so that

its anterior and posterior surfaces lie in front of the corresponding surfaces of the shaft. The groove of the trochlea winds backwards and laterally, as it is traced from the anterior to the posterior surface of the bone, and it is wider, deeper and more symmetrical posteriorly. Anteriorly, the medial flange of the pulley is much longer than the lateral, and the surface adjoining its projecting medial margin is convex to accommodate itself to the medial part of the upper surface of the coronoid process of the ulna.

The *capsular ligament of the elbow-joint* extends upwards for some distance beyond the articular surface to gain attachment to the humerus. Anteriorly it passes to the upper limits of the radial and coronoid fossæ, so that both these bony depressions are intracapsular and therefore lined with synovial membrane. Medially it is attached to the medial non-articular aspect of the projecting lip of the trochlea and to the root of the medial epicondyle. Posteriorly it ascends to, or almost to, the upper margin of the olecranon fossa, which is therefore intracapsular and covered with synovial membrane. Laterally it skirts the lateral borders of the trochlea and capitulum, lying medial to the lateral epicondyle.

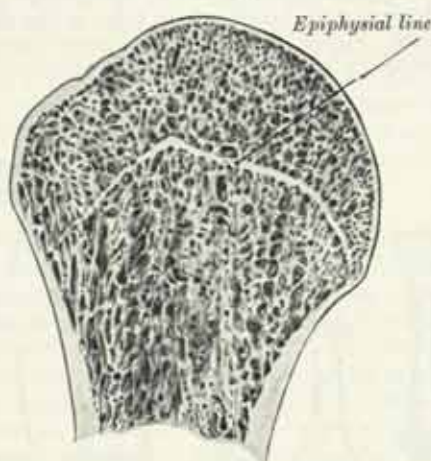
The muscular impression on the *medial epicondyle* gives attachment to the common origin of the superficial group of flexor muscles. They arise from the epiphysis for the epicondyle, but are entirely outside the articular capsule of the elbow-joint. The impression on the *lateral epicondyle* gives attachment to the common origin of the superficial group of extensor muscles of the forearm. These arise from the lateral side of the lower humeral epiphysis, and, like the flexors, are situated outside the articular capsule. A small area on the posterior surface of the lateral epicondyle gives origin to the anconeus (fig. 388). The medial epicondyle is directed backwards a little at its extremity, whereas the lateral epicondyle shows a slight trend in the opposite direction.

It should be observed that when the humerus is at rest by the side the medial epicondyle lies on a plane which is posterior to the plane of the lateral epicondyle, so that the bone *appears* to be rotated medially. In this position the head of the humerus is directed almost equally backwards and medially, and the posterior surface of the shaft looks laterally as well as backwards. This position of the bone must be kept in mind when the movements of the arm and forearm are considered (pp. 486 and 493).

A hook-shaped process of bone termed the *supracondylar process*, varying from 2 mm. to 20 mm. in length, is occasionally found projecting from the anteromedial surface of the shaft of the humerus, about 5 cm. above the medial epicondyle. It is curved downwards and forwards, and its pointed end is connected to the medial border, just above the epicondyle, by a fibrous band which gives origin to a portion of the pronator teres; the foramen completed by this fibrous band usually transmits the median nerve and brachial artery. Sometimes the nerve alone is transmitted through it, or the nerve may be accompanied by the ulnar artery, in cases of high division of the brachial artery. A groove, which lodges the artery and nerve, is usually found behind the process. This foramen is the homologue of the supracondylar foramen found in many animals, and probably serves in them to protect the nerve and artery from compression during the contraction of the muscles in this region.

Ossification * (fig. 392).—The humerus is ossified from eight centres—one for each of the following parts: the shaft, the head, the greater tubercle, the lesser tubercle, the capitulum and lateral part of the trochlea, the medial part of the trochlea, and one for each epicondyle. The centre for the shaft appears near its middle in the eighth week of intrauterine life, and gradually extends towards the ends, which at birth are cartilaginous. Before birth, or early in the first year, ossification begins in the head, during the second year in the greater tubercle, and during the fifth in the lesser tubercle. By the sixth year the centres for the head and

FIG. 391.—A longitudinal section through the head of the right humerus.

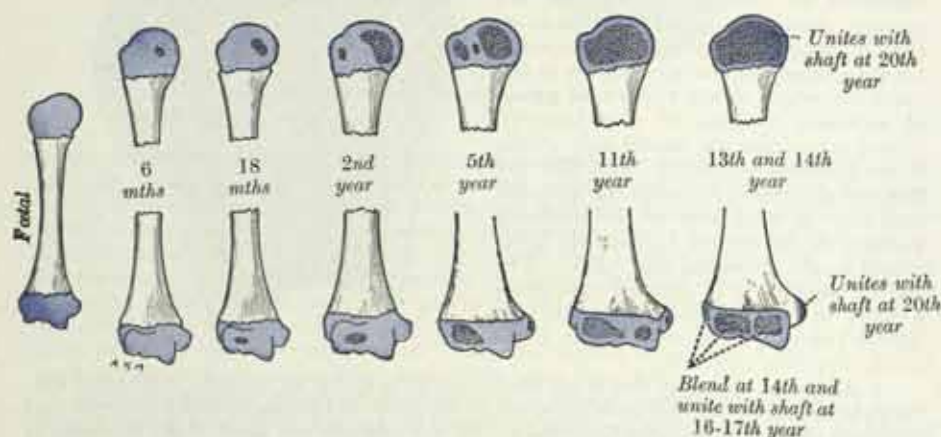


* The times of appearance of the epiphyseal centres of ossification and of the union of the epiphyses with the shafts of the limb bones are based, for the most part, on the observations of F. G. Parsons and D. A. Davies, *J. Anat.*, 62, 1927, and J. W. Pryor, *J. Anat.*, 62, 1928.

tubercles have joined to form a single large epiphysis, which is hollowed out on its inferior surface (fig. 391) to adapt it to the somewhat conical upper end of the diaphysis. It fuses with the shaft of the humerus about the twentieth year. The lower end is ossified as follows. During the second year ossification begins in the capitulum and extends medially to form the chief part of the articular surface; the centre for the medial part of the trochlea appears about the eleventh or twelfth year. Ossification begins in the medial epicondyle about the fifth year, and in the lateral about the twelfth year. The centre for the lateral epicondyle fuses with those for the trochlea and capitulum (fig. 392) during the fourteenth year, and the large epiphysis thus formed unites with the shaft about the sixteenth or seventeenth year. The centre for the medial epicondyle forms a separate epiphysis, which is entirely extra-capsular (figs. 386, 388) and is placed on the posteromedial aspect of the epicondyle. It is separated from the rest of the lower epiphysis by a downgrowth from the shaft, with which it unites about the twentieth year.

Applied Anatomy.—The upper epiphysis of the humerus, is the last to join the shaft, and the length of the bone is due mainly to growth from the upper epiphyseal plate. Hence, in cases of amputation through the arm in young subjects, the humerus continues to grow considerably, and the lower end of the bone, which immediately

FIG. 392.—Stages in the ossification of the humerus.



after the operation was covered with a thick cushion of soft tissue, begins to project, rendering the stump conical.

Fractures of the humerus are common and may occur at almost any level. This bone is fractured by muscular action probably more frequently than any other long bone; it is usually the shaft of the bone, just below the insertion of the deltoid, which is thus broken. The radial nerve may be injured as it lies in its groove, or may become involved in growth of callus during the process of repair. Further, non-union is frequent and indeed it is commoner in the humerus than in any other bone except the tibia. Fractures of the upper end of the bone may damage the axillary (circumflex) nerve, while fractures of the medial epicondyle often are complicated by damage to the ulnar nerve.

THE RADIUS (figs. 393-396)

General features.—The **radius** is the lateral bone of the forearm. The upper and lower ends are both expanded, but the lower end is much the wider of the two. The shaft increases in breadth rapidly towards the lower end, is convex to the lateral side and is concave forwards in its lower part. Examination of the shaft, therefore, will enable a given radius to be assigned correctly to its appropriate side of the body.

The upper end of the radius includes the head, the neck and the tuberosity. The **head** is disc-shaped and its upper surface is hollowed out to form a shallow cup for articulation with the capitulum of the humerus. The *articular circumference* of the head is smooth and is deepest on the medial side, where it articulates with the

radial notch of the ulna. Its posterior surface can be felt through the skin as it lies at the bottom of a small depression which is visible in the living subject on the lateral side of the posterior surface of the extended elbow. The *neck* of the radius is the constricted part below the head, and is overhung by it, especially on the lateral side. The *tuberosity* of the radius is placed below the medial part of the neck. Its posterior part is roughened but its anterior part is usually smooth.

The *shaft* of the radius is gently curved with the convexity directed to the lateral side. On transverse section it is triangular in outline, but only one of its three borders is sharp and easy to identify. The *interosseous border* is a salient crest, except at its upper end, where it approaches the lower part of the tuberosity. At its lower end it forms the posterior margin of a small, elongated, triangular area, which constitutes an additional—medial—surface for this end of the bone. In its lower three-fourths this border gives attachment to the interosseous membrane, which connects the opposed borders of the two bones of the forearm. The *anterior border* can be recognised without difficulty at its upper and lower ends, but it is rounded and indefinite in the intervening region. It commences just below the anterolateral part of the tuberosity and runs downwards with an inclination towards the lateral side. This part is often described as the *anterior oblique line* of the radius. The lower part of the anterior border forms a sharp crest along the lateral margin of the anterior surface, and can be recognised easily through the skin. The *posterior border* is clearly defined in its middle third only. Above, it runs obliquely upwards and medially towards the postero-inferior part of the tuberosity. Below, it forms a rounded ridge which is difficult to trace.

The *anterior surface* lies between the anterior and the interosseous borders. It is slightly concave from side to side and curves forwards at its lower end. A little above its middle it presents a nutrient foramen, which is directed upwards. The *posterior surface*, which is bounded by the interosseous and the posterior borders, is generally flat but may be slightly hollowed out in its upper part. The *lateral surface* is gently convex in all directions. Above, owing to the obliquity of the upper parts of the anterior and posterior borders, it encroaches on the anterior and posterior aspects of the bone, and this widened portion is usually slightly roughened. A finely irregular, rough surface occupies an oval area near the middle of the shaft, but below this the surface of the bone is smooth and featureless.

The *lower end* is the widest part of the radius, and is four-sided on transverse section. Its *lateral surface* is slightly rough and projects downwards beyond the rest of the bone to form the *styloid process*. This projection can be felt through the skin, when the tendons which conceal it in the living body are relaxed. The inferior surface of the lower end (fig. 399) is smooth and takes part in the formation of the wrist-joint. This *carpal articular surface* is divided by a faint ridge into a medial and a lateral area. The medial area is quadrangular: the lateral area is triangular and covers the medial side of the styloid process. The *anterior surface* is a thick, prominent ridge, which can be palpated in the living subject, despite the overlying tendons. It lies nearly 2 cm. above the base of the thenar eminence. The *medial surface* is occupied by the *ulnar notch*, which provides a smooth strip, concave from before backwards, for articulation with the head of the ulna in the inferior radio-ulnar joint. The *posterior surface* is marked by the *dorsal tubercle*, which is limited on its medial side by a narrow, oblique groove. It lies in line with the cleft between the index and middle fingers and can readily be felt through the skin. A wide, shallow groove lies on the lateral side of the tubercle and is divided into two parts by a very faint vertical ridge. A similar, but undivided, groove marks the medial part of the posterior surface.

Particular features.—The upper surface of the *head* and its *articular circumference* are everywhere covered with hyaline cartilage. The upper margin of the head fits into the groove between the capitulum and the trochlea, and, when the forearm is flexed, it invades the radial fossa. The articular circumference articulates with the radial notch of the ulna, and in the rest of its extent is surrounded by the annular ligament, within which it rotates in pronation and supination. The *neck* of the bone is surrounded by the narrower, lower part of the annular ligament, but is separated from it by a protrusion of the synovial membrane of the superior radio-ulnar joint.

The rough, posterior part of the *tuberosity* gives insertion to the biceps muscle,

FIG. 393.—The bones of the left forearm. Anterior aspect.

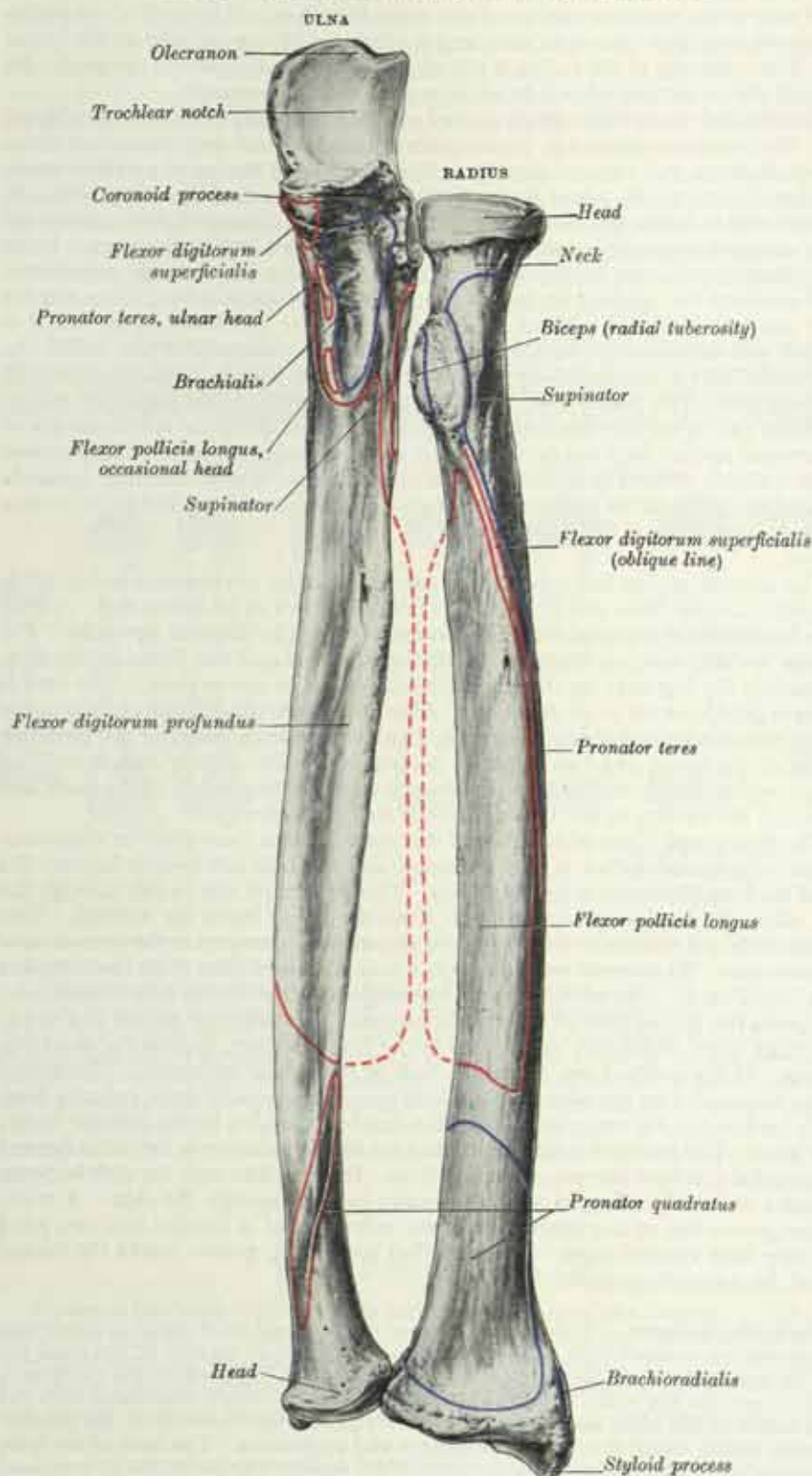
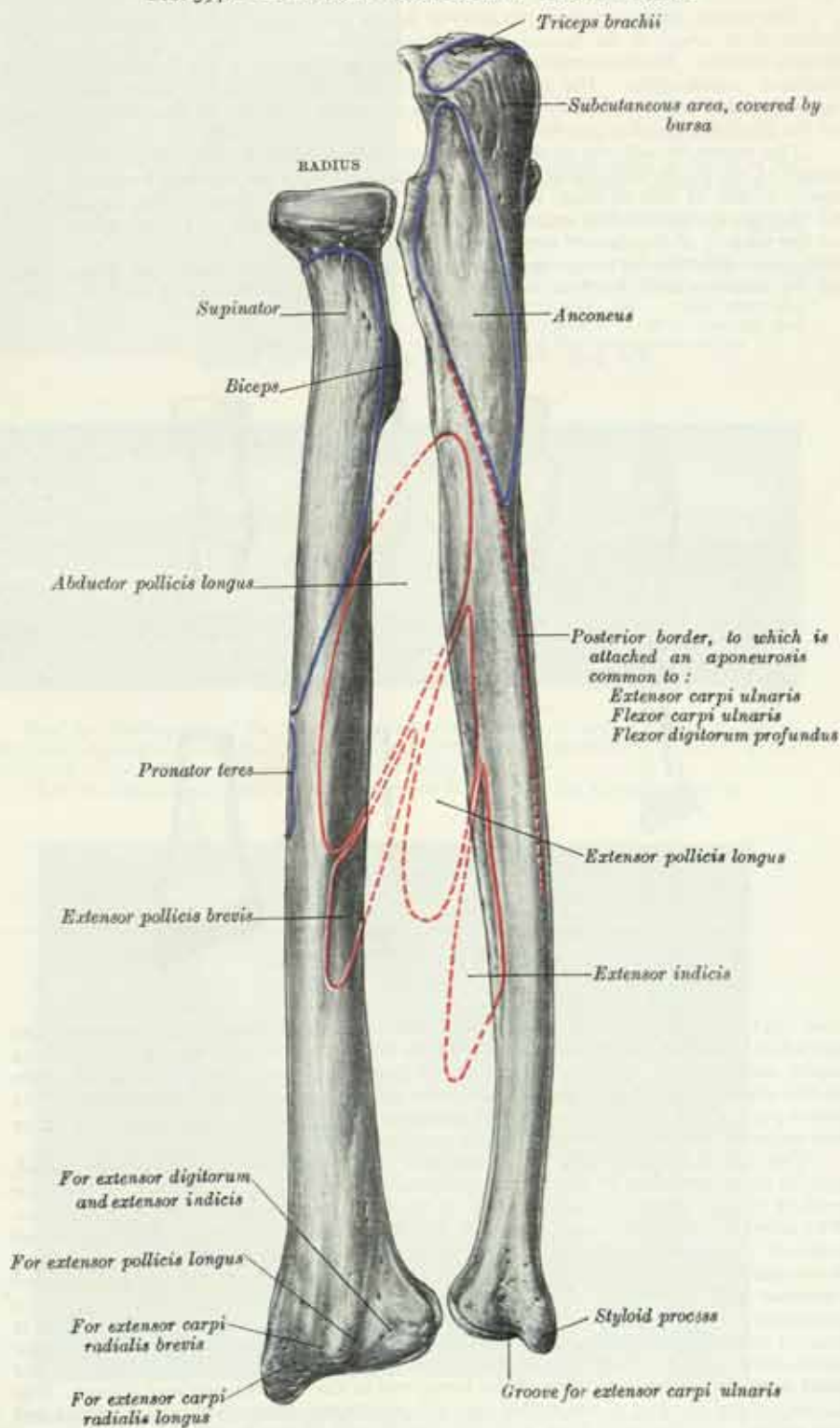


FIG. 394.—The bones of the left forearm. Posterior aspect.

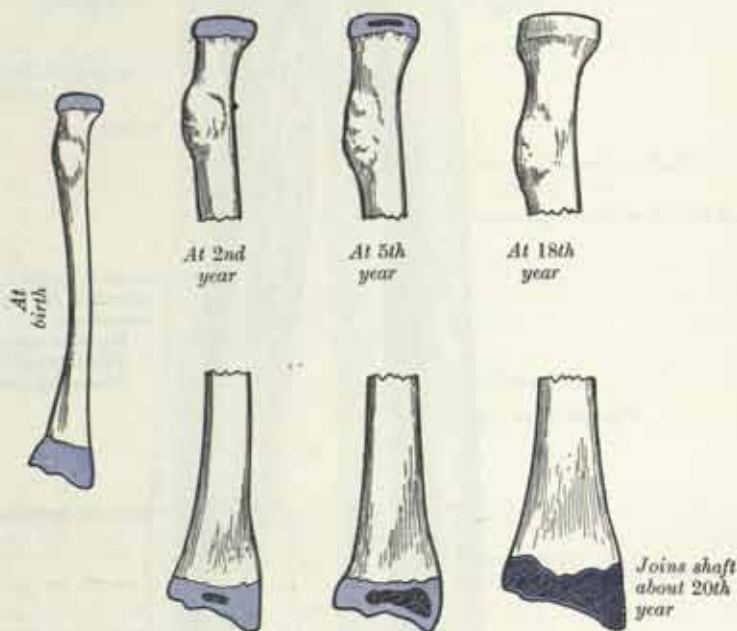


but its smooth, anterior part is separated from the tendon by a bursa. A little below the tuberosity the oblique cord is attached to the radius.

The upper, oblique part of the *anterior border* and a variable portion of the border below gives origin to the thin, expanded radial head of the flexor digitorum superficialis muscle. Its conspicuous lower part gives attachment to the lateral edge of the extensor retinaculum. The small, triangular area in front of the lower end of the interosseous border and above the ulnar notch gives insertion to the deepest fibres of the pronator quadratus muscle.

The upper two-thirds of the *anterior surface* provides an extensive area for the origin of the flexor pollicis longus muscle, which conceals the nutrient foramen. The lower fourth of this surface, together with the triangular area on the medial side of the bone, receives the insertion of the pronator quadratus. The roughened area at the middle of the *lateral surface* is situated at the region of maximum curvature and gives insertion to the pronator teres. Above, the surface widens at the expense of the anterior and posterior surfaces, and the elongated V-shaped area (figs. 393

FIG. 395.—Stages in the ossification of the radius.



and 394) provides insertion for the supinator muscle. Below the insertion of the pronator teres the lateral surface is smooth and is covered by the tendons of the radial extensors of the wrist. The upper part of the *posterior surface* gives origin to the abductor pollicis longus, above, and the extensor pollicis brevis, below. The lower part of this surface is devoid of muscular attachments but is closely covered by the extensor pollicis brevis and longus muscles.

The *styloid process* of the radius projects to a lower level than the ulnar styloid, and its tip is concealed by the tendons of the abductor pollicis longus and the extensor pollicis brevis. It gives attachment by its tip to the lateral ligament of the wrist-joint. The lateral surface of the lower end of the radius a little above the styloid process receives the insertion of the brachioradialis and is crossed obliquely, from above downwards and forwards, by the tendons of the abductor pollicis longus and extensor pollicis brevis. The ridge-like *anterior surface* of the lower end gives attachment to the palmar radiocarpal ligament of the wrist-joint. The *ulnar notch* is limited below by a smooth ridge to which the base of the articular disc of the inferior radio-ulnar joint is attached. A small protrusion of the synovial membrane of the joint extends upwards in front of the lower end of the interosseous membrane. The lateral, triangular part of the *carpal articular surface* articulates with the scaphoid and the medial, quadrangular part with the lateral part of the lunate bone. When the hand is adducted fully the whole of the upper surface of the lunate bone comes into contact with the radius.

The *dorsal tubercle* gives attachment to a slip from the extensor retinaculum and



FIG. 1.—Radiograph of the hand and wrist in full flexion, viewed from the side.

The arrows point, 1, to the capitate bone: 2, to the lunate bone: 3, to the tubercle of the scaphoid bone: and, 4, to the tubercle of the trapezium.

Compare with fig. 2 and note the relative positions of the capitate and lunate, and the lunate and radius.



Fig. 2.—Radiograph of the hand and wrist, viewed from the side. The long axes of the third metacarpal bone, the capitate and the lunate are, approximately, in line with the long axis of the radius. The arrows point as in fig. 1.

Note the relative positions of the capitate and lunate, and the lunate and radius.



FIG. 3.—Radiograph of the hand and wrist in full extension, viewed from the side. The arrows point as in fig. 1.

Compare with fig. 2 and note the alterations in the relative positions of the capitate and lunate bones, and the lunate bone and the radius.



FIG. 1.—Radiograph of the hand in full adduction. The arrows point to the scaphoid bone on the lateral side and to the pisiform bone on the medial side. Note that the shadow of the pisiform bone overlaps the shadow of the tip of the styloid process of the ulna.

Compare with fig. 2 and observe that the movements occur at both the radiocarpal and intercarpal joints.



FIG. 2.—Radiograph of the same hand in full abduction. The arrows point to the hamate and pisiform bones.

Compare with fig. 1 and note : (1) that the scaphoid and lunate bones have passed medially so that the latter articulates to a large extent with the articular disc of the inferior radio-ulnar joint : (2) that the pisiform is now widely separated from the styloid process of the ulna : (3) that the scaphoid, having rotated round a transverse axis, is much foreshortened : (4) that the apex of the hamate bone has been thrust away from the lunate by the rotation of the capitate around an antero-posterior axis : (5) that a gap has opened up between the distal portions of the hamate and triquetral bones : and (6) that the long axes of the capitate and lunate bones are now almost in the same straight line.

is grooved on its medial side by the extensor pollicis longus tendon. The wide, shallow groove to the lateral side of the tubercle contains the tendons of the extensor carpi radialis longus, laterally, and the extensor carpi radialis brevis, medially, together with their synovial sheaths. The medial part of the posterior surface is grooved by the tendons of the extensor digitorum, but the extensor indicis and the posterior interosseous nerve intervene between them and the bone. The lower margin of the posterior surface gives attachment to the dorsal radiocarpal ligament.

Ossification (figs. 395, 396).—The radius is ossified from three centres: one for the shaft, and one for each end. That for the shaft appears near the middle in the eighth week of intrauterine life. About the close of the first year, ossification begins in the lower end; and at the fourth year, in the upper end. The upper epiphysis fuses with the shaft at the age of seventeen or eighteen years, the lower about the age of twenty. An additional centre sometimes appears in the tuberosity about the fourteenth or fifteenth year.

FIG. 396.—The epiphyseal lines of the left radius in a young adult. Anterior aspect.



The line of attachment of the articular capsule of the wrist-joint is in blue.

THE ULNA (figs. 393, 394, 397)

General features.—The **ulna** is the medial bone of the forearm and is parallel with the radius when the forearm is supine. The upper end is thick, strong and hook-like (fig. 397), the concavity of the hook being directed forwards. The lateral border of the shaft is a thin, sharp crest. This information is sufficient to enable the student to refer a given ulna correctly to its appropriate side of the body. The bone diminishes in size from its upper to its lower end, which bears a small, rounded enlargement termed the head of the ulna. The shaft is triangular on section.

The bone is not perfectly straight, and shows a slight but appreciable double curve. Throughout its whole length it forms a gentle curve, the convexity of which is directed backwards. In addition, the upper half or more shows a slight curvature to the lateral side, and the lower half or less a similar curvature in the opposite direction.

The **upper end** of the ulna (fig. 397) displays two substantial processes, named the olecranon and the coronoid process, and two articular areas, termed the trochlear and radial notches, which articulate, respectively, with the humerus and the radius.

The **olecranon** is the uppermost part of the bone. It is bent forwards at its summit to form a prominent beak, which is received into the olecranon fossa of the humerus when the forearm is extended. Its posterior surface, which is smooth and triangular in outline, can easily be felt through the skin, and its upper border forms the point of the elbow. When the elbow is extended, this border can be felt on, or just above, the line joining the two epicondyles of the humerus, but when the elbow is flexed, it descends, and the three bony points then form the angles of an isosceles triangle. The anterior surface of the olecranon is smooth and articular, and forms the upper part of the trochlear notch. The base of the olecranon is constricted where it joins the shaft, and this is the narrowest part of the upper end of the ulna.

The **coronoid process** forms a bracket-like projection from the front of the bone immediately below the olecranon. Its upper surface forms the lower part of the trochlear notch and is therefore smooth and articular. The upper part of the lateral surface presents the shallow **radial notch** for articulation with the side of the head of the radius, and the bone below it is hollowed out to make room for the tuberosity of the radius during the movements of pronation and supination. The anterior surface of the process is triangular in shape and bears on its lower part the

rough *tuberosity of the ulna*. The medial border of the process is sharp and bears a small, but prominent, tubercle at its upper end.

The *trochlear notch* articulates with the trochlea of the humerus and is shaped accordingly. It is formed by the anterior surface of the olecranon and the superior surface of the coronoid process. The bone is constricted at the junction between these two areas, and they may be separated completely by a narrow, roughened strip.

FIG. 397.—The upper part of the left ulna. Lateral aspect.



A smooth ridge, which corresponds to the groove of the trochlea, divides the notch into a larger, medial, and a smaller, lateral part. The medial part conforms to the large flange of the trochlea of the humerus.

The *radial notch* (fig. 397) is an oblong, articular depression on the upper part of the lateral aspect of the coronoid process. It articulates with the articular circumference of the head of the radius, and is separated from the lateral part of the trochlear notch by a smooth ridge.

The **lower end** of the ulna is slightly expanded and comprises the rounded head and the styloid process. The *head* forms a surface elevation on the medial part of the posterior aspect of the wrist when the hand is pronated, and it can be gripped between the finger and thumb when the supinated hand is flexed passively. It presents a convex articular surface on its lateral side for articulation with the ulnar notch of the radius. Its inferior surface (fig. 399) is smooth and is separated from the carpus by the articular disc of the inferior radio-ulnar joint, which is attached by its apex to the small rough area interposed between the articular surface and the styloid process. The *styloid process* is a short, rounded projection which springs from the posteromedial aspect of the lower end of the ulna. Its tip can be felt through the skin on the posteromedial aspect of the wrist, where it lies about 1 cm. above the level of the tip of the styloid process of the radius. On the dorsal surface a shallow groove intervenes between the head of the ulna and the styloid process.

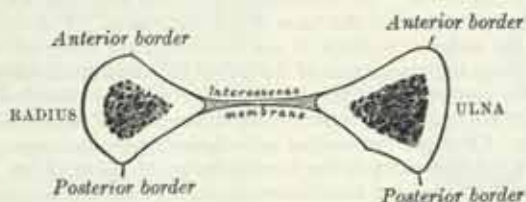
The **shaft** of the ulna is triangular on section (fig. 398) in its upper three-fourths, but is almost cylindrical in its lower fourth. The surfaces of the shaft are anterior, posterior and medial; the borders, interosseous, posterior and anterior.

The *interosseous border* is the lateral margin of the bone and forms a conspicuous crest in its middle two-fourths. The upper part becomes continuous with the posterior border of the depression which lies below the radial notch and is here termed the *supinator crest*; its lower part fades away on the cylindrical, lower portion of the shaft. The *anterior border* is thick and rounded. It commences above at the medial side of the tuberosity of the ulna and inclines backwards below where it can usually be traced to the base of the styloid process. The *posterior border*, also thick and rounded, commences at the apex of the posterior aspect of the olecranon and curves laterally as it descends. Below, it is very indistinct as it descends to the styloid process. *Throughout its whole length this border can easily be felt through the skin.* It lies at the bottom of a longitudinal furrow, which is seen best when the elbow is in full flexion.

The *anterior surface* of the ulna (fig. 393) is placed between the interosseous and

the anterior borders, and is gently (sometimes deeply) grooved in its long axis. A little above the middle of the bone this surface presents the nutrient foramen (fig. 393), which is directed upwards and transmits a branch of the anterior interosseous artery. In its inferior part it is crossed obliquely by a rough strip, of variable prominence, which runs downwards from the interosseous border to the anterior border. The *medial surface* is bounded by the anterior and the posterior borders

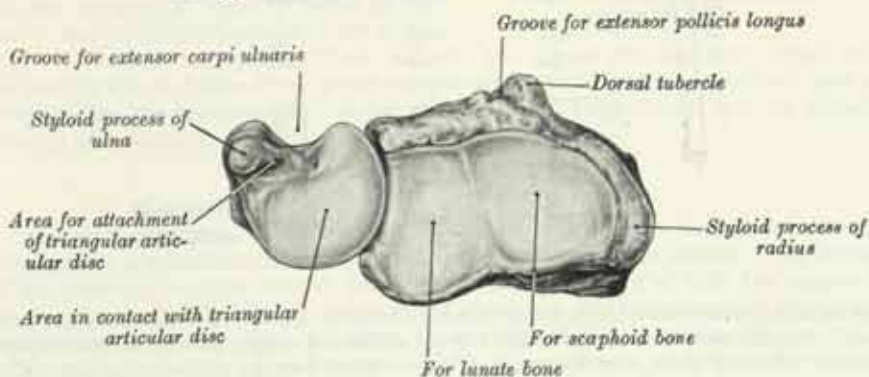
FIG. 398.—A transverse section through the left radius and ulna, showing the attachment of the antebrachial interosseous membrane. Upper aspect.



Convex from side to side, it is smooth and featureless. The *posterior surface* (fig. 394) lies between the posterior and the interosseous borders. It is subdivided into three areas, of which the uppermost is limited by an oblique line—not always easily discernible—which runs upwards and laterally from the junction of the middle and upper thirds of the posterior border to the posterior end of the radial notch (fig. 397). The region below this line is divided into a larger medial and a narrower lateral strip by a vertical ridge, usually distinct in its upper three-fourths but difficult to determine in its lower part.

Particular features.—The upper surface of the *olecranon* gives attachment, in front, to the capsular ligament of the elbow-joint; in its posterior two-thirds, which

FIG. 399.—The lower ends of the right radius and ulna.



are roughened, it provides insertion for the tendon of the triceps muscle. Occasionally these two areas are separated by a smooth bursal area. Its medial surface is marked in its upper part by a rough elevation, which gives attachment to the posterior and oblique bands of the ulnar collateral ligament of the elbow-joint and the ulnar head of the flexor carpi ulnaris. Its lower part is smooth and gives origin to the uppermost fibres of the flexor digitorum profundus. The lateral surface of the process, and the adjoining part of the posterior surface of the shaft down to the oblique line already mentioned (fig. 397), give insertion to the anconeus muscle. Its posterior surface is separated from the skin by a bursa.

The anterior surface of the *coronoid process*, including the tuberosity of the ulna, receives the insertion of the brachialis muscle. Its medial border is sharp, and a small, rounded tubercle is situated at its upper end. This tubercle gives attachment to the oblique and anterior bands of the ulnar collateral ligament of the elbow-joint and to the lowest part of the humero-ulnar head of the flexor digitorum superficialis muscle. Below the tubercle the margin gives origin to the ulnar head of the pronator teres, and below that to an occasional ulnar head of the flexor pollicis longus. The medial

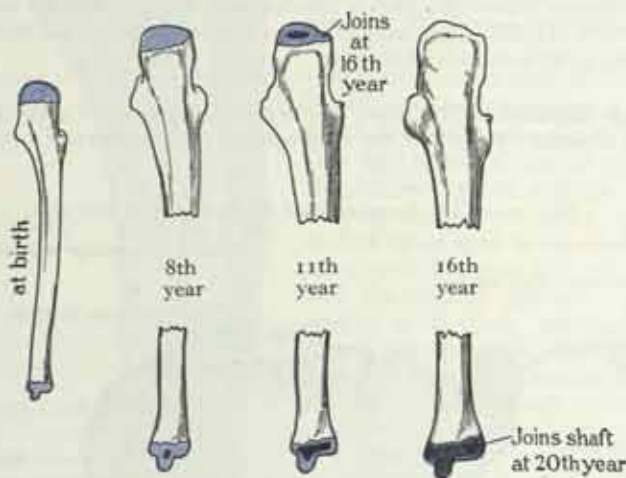
surface of the process is concave and gives origin to fibres of the flexor digitorum profundus. The anterior and posterior borders of the radial notch provide attachment for the annular ligament of the radius. The depressed area below the notch is limited behind by the *supinator crest*; the supinator muscle arises from the crest and from the adjoining part of the depression.

The part of the *trochlear notch* which is formed by the olecranon is, typically, divided into three areas. Of these the most medial faces forwards and slightly medially and is hollowed out to fit the medial flange of the trochlea: the intermediate area is flattened and fits the lateral flange of the trochlea; the most lateral area, which forms a narrow strip directed to the radial side, comes into contact with the trochlea only when the elbow is extended. The constriction of the articular surface is more pronounced than the constriction of the base of the olecranon. The resulting small non-articular parts of the anterior surface of the olecranon are covered in the fresh specimen and in life by tag-like processes of the synovial membrane which contain a little fat (fig. 513). The *coronoid part* of the trochlear notch is divided into medial and lateral parts, which correspond, respectively, to the medial and intermediate parts of the olecranon area. Of these the medial is hollowed out much more than the lateral, in conformity with the convexity of the medial flange of the trochlea. The medial and anterior borders of this area give attachment to the medial and anterior portions of the capsular ligament of the elbow-joint.

The carrying angle and its functional importance are described on p. 493.

The subcutaneous *posterior border* of the ulna gives attachment to the deep fascia of

FIG. 400.—Stages in the ossification of the ulna.



the forearm, which acts, in its upper three-fifths, as an additional origin for the flexor carpi ulnaris, and in its middle third as an additional origin for the extensor carpi ulnaris. Both of these muscles are therefore connected to the posterior border. The *interosseous border* is usually continuous above with the supinator crest. Except at its upper end it gives attachment to the interosseous membrane of the forearm. The rounded *anterior border* is covered in its upper three-fourths by the flexor digitorum profundus, to which it gives origin.

The *anterior surface* gives origin in its upper three-fourths to the flexor digitorum profundus. In the same extent the muscle arises also from the anterior border and the *medial surface*, extending upwards on to the medial sides of the coronoid process and the olecranon. The rough strip which crosses the lower fourth of the anterior surface provides origin for the pronator quadratus. The anconeus is inserted into the *posterior surface* above the oblique line already mentioned, and extends upwards on to the lateral aspect of the olecranon. The narrow strip between the interosseous border and the vertical ridge gives part origin to three of the deep muscles of the forearm. The abductor pollicis longus arises from its upper fourth, and a ridge may separate this area from the succeeding fourth, which gives attachment to the extensor pollicis longus. The extensor indicis is attached to the third fourth of this area. The broad strip to the medial side of the vertical ridge is devoid of muscular attachments but is covered by the extensor carpi ulnaris, the tendon of which occupies the groove on the posterior aspect of the lower end of the bone. The ulnar collateral ligament of the

wrist-joint is attached to the tip of the *styloid process*. The articular disc separates the head of the ulna from the medial part of the lunate bone and, in adduction of the hand, from the triquetral bone.

FIG. 401.—The epiphyseal lines of the left ulna in a young adult. Lateral aspect.

Ossification (figs. 400, 401).—The ulna is ossified from three centres: one each for the shaft, the lower end, and the top of the olecranon. Ossification begins near the middle of the shaft, about the eighth week of intrauterine life, and soon extends through its greater part. Between the seventh and eighth years, the centre for the lower end appears in the middle of the head, and extends into the styloid process. About the eleventh year, a centre appears in the olecranon and forms a thin scale for the top of the process, the chief part of the process being formed by an upward extension of the shaft; sometimes the upper part of the olecranon is ossified from two centres. The upper epiphysis joins the shaft about the sixteenth, the lower about the twentieth year. The former may take part in the formation of the trochlear notch although it does not usually do so.



The lines of attachment of the articular capsules are in blue.

THE SKELETON OF THE HAND

The skeleton of the hand has three segments: (1) the carpal or wrist bones (2) the metacarpal bones or bones of the palm; and (3) the phalanges or bones of the digits. In the description which follows, the terms *proximal* and *distal* will be used to the exclusion of the terms *superior* and *inferior* hitherto employed, and in addition the terms *palmar* and *dorsal*, which are self-explanatory, will be utilised instead of *anterior* and *posterior*, respectively.

THE CARPUS (figs. 402-405)

General features.—The **carpus** comprises eight short bones, which are arranged in a proximal and a distal row, each containing four bones. The bones of the proximal row are named, from the lateral to the medial side, the *scaphoid*, *lunate*, *triquetral* and *pisiform*; those of the distal row, the *trapezium*, the *trapezoid*, the *capitate* and the *hamate*. Of these, the pisiform is placed on the palmar surface of the triquetral and is separated from the other carpal bones, all of which articulate with their immediate neighbours. The other bones of the proximal row form an arch convex proximally, which articulates with the radius and the articular disc of the inferior radio-ulnar joint. The concavity of the arch is directed distally and forms a mortise for the proximally projecting parts of the capitate and hamate bones. In this way the two rows are locked to each other and stability is assured.

The dorsal surface of the whole carpus is gently convex from side to side, but the palmar surface is deeply concave, owing to the presence of certain forward projections on its lateral and medial borders. The *pisiform bone* lies at the medial part of the proximal border of the muscular prominence (hypotheneal eminence) which marks the medial portion of the palm, and its position on the front of the triquetral makes it easy to feel through the skin. In addition, the distal part of the *hamate bone* bears a *hook-like process* on its palmar surface. The concavity of the hook is directed towards the lateral side and its tip can be identified in the living subject. It lies 2.5 cm. distal to the pisiform and in line with the ulnar border of the ring finger. On deep pressure in this situation the superficial division of the ulnar nerve can be rolled from side to side over this bony point. The projecting lateral border of the

FIG. 402.—The carpus and metacarpus of the left hand. Palmar aspect.

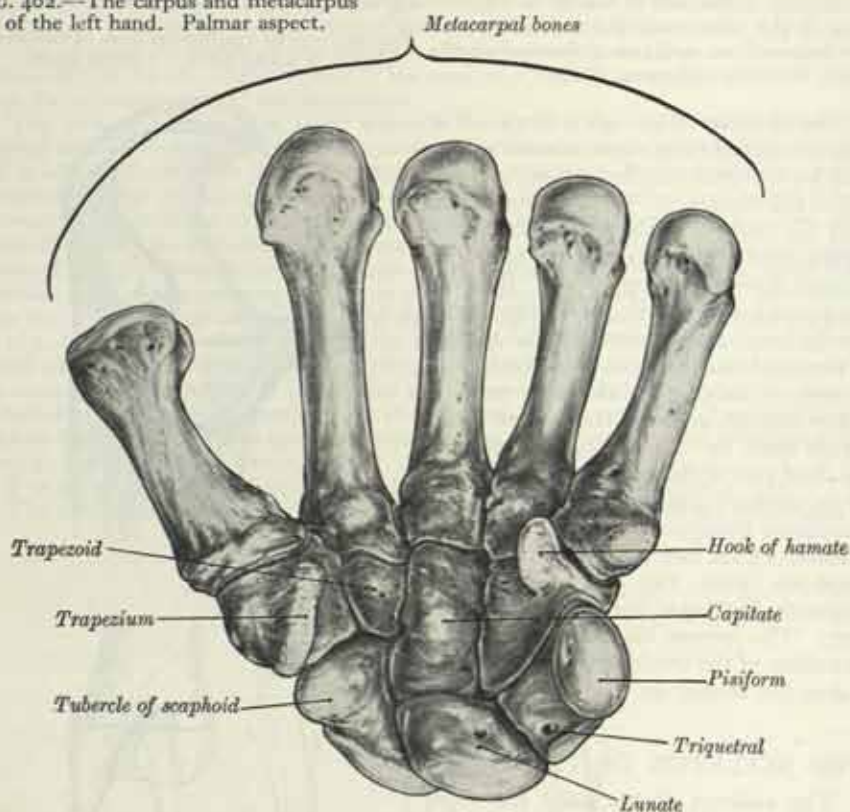
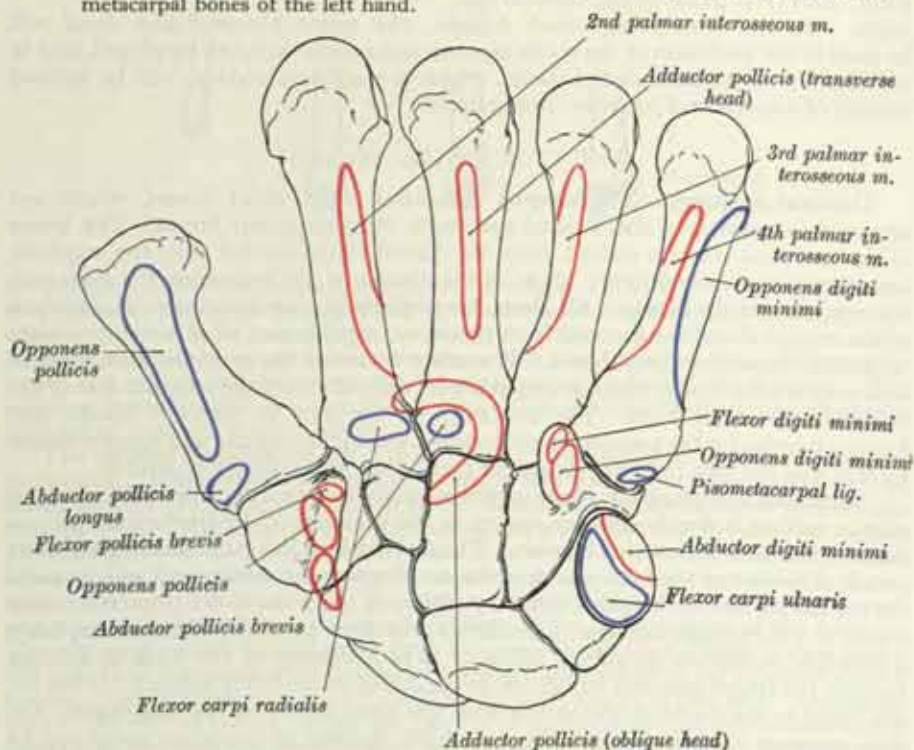


FIG. 403.—Diagram showing the muscles attached to the palmar aspects of the carpal and metacarpal bones of the left hand.

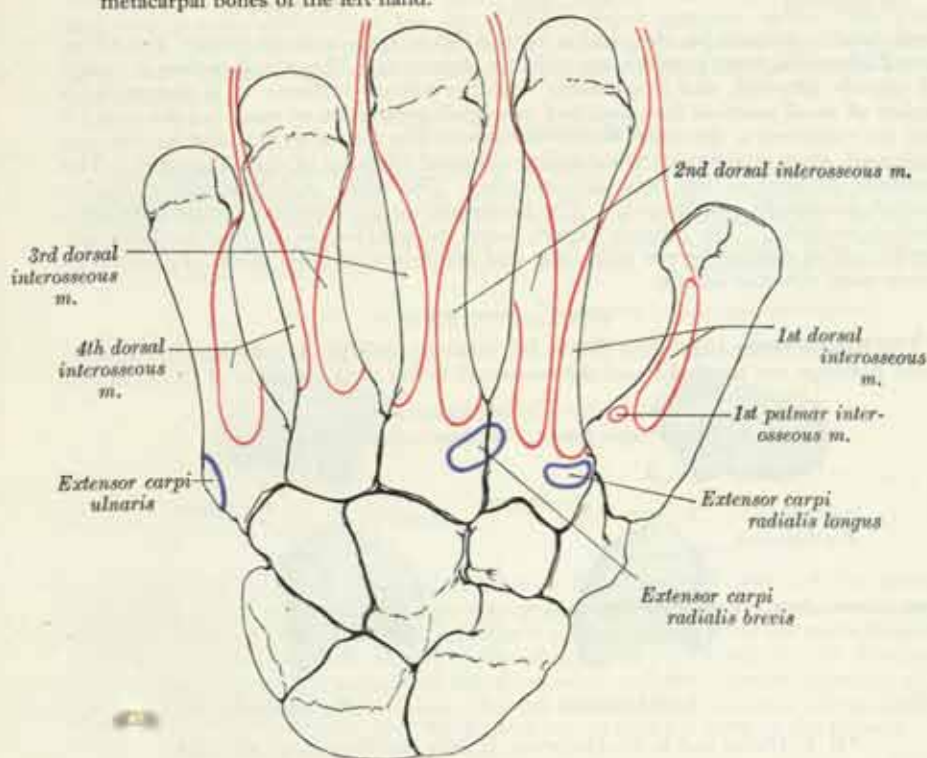


The dorsal interosseous muscles are not shown.

FIG. 404.—The carpus and metacarpus of the left hand. Dorsal aspect.



FIG. 405.—Diagram showing the muscles attached to the dorsal aspects of the carpal and metacarpal bones of the left hand.



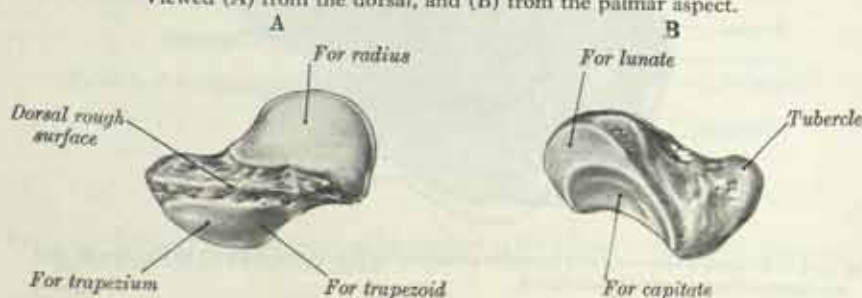
carpal groove is formed by the *tubercle of the scaphoid* and the *tubercle of the trapezium*. The tubercle is placed on the distal part of the anterior surface of the scaphoid and can be felt—and sometimes seen—as a small, rounded knob, at the medial part of the proximal border of the muscular prominence (thenar eminence) which marks the lateral portion of the palm. The tubercle of the trapezium forms a rounded ridge which runs vertically across the anterior surface of the bone, being slightly hollowed out on its medial side. It lies immediately distal and slightly lateral to the tubercle of the scaphoid, and can be felt only on deep pressure. The margins of the groove give attachment to a strong fibrous retinaculum, which retains the flexor tendons within an osteofibrous, carpal canal and so increases the efficiency of the flexor muscles. In addition, the retinaculum serves to increase the stability of the carpus. The palmar and dorsal surfaces of the carpal bones—apart from the triquetral and the pisiform—are rough for the attachment of ligaments (radiocarpal, intercarpal and carpometacarpal).

THE INDIVIDUAL CARPAL BONES

THE SCAPHOID BONE

The **scaphoid bone** (figs. 406, A and B) is named from its fancied resemblance to a boat. It is the largest bone in the proximal row and lies with its long axis directed distally, laterally and slightly forwards. The tubercle forms a rounded elevation on the distal part of the *palmar surface* and is directed slightly to the lateral side. It gives attachment to the flexor retinaculum and a few fibres of the abductor pollicis

FIG. 406.—The left scaphoid bone.
Viewed (A) from the dorsal, and (B) from the palmar aspect.

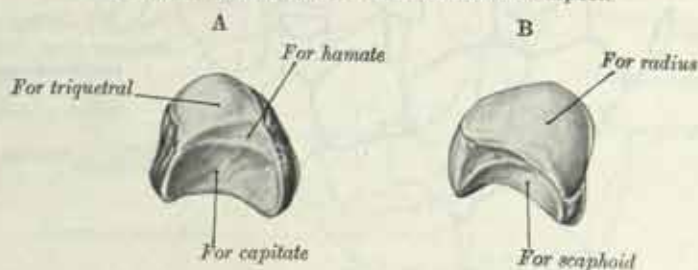


brevis, and is crossed by the tendon of the flexor carpi radialis, which should be relaxed when the bony prominence is being examined. The *dorsal surface* is rough and slightly grooved, and is narrower than the palmar surface. It is pierced by a number of small nutrient foramina and in a small proportion of cases (13 per cent.) * these are restricted to the distal half of the bone. The *lateral surface*, also narrow and roughened, gives attachment to the radial collateral ligament of the wrist-joint. The remaining surfaces of the bone are articular. The *radial surface* is convex and is directed proximally and laterally. The *lunate surface* is a flattened, narrow semilune, directed medially. The *capitate surface*, large and concave, is directed medially and distally. The *surface for the trapezium and the trapezoid bones* forms a continuous convex area, directed distally.

THE LUNATE BONE

The **lunate bone** (figs. 407, A and B), distinguished by its crescentic outline, is placed between the scaphoid and the triquetral bones in the middle of the proximal

FIG. 407.—The left lunate bone.
A. Distomedial aspect. B. Proximolateral aspect.



* B. E. Oblatz and B. M. Halbstein, *J. Bone and Joint Surg.*, xx, 1938.

row of the carpus. The rough, *palmar surface*, almost triangular in outline, is larger and wider than the rough, *dorsal surface*. The smooth, convex, *proximal surface* articulates with the radius and the articular disc of the distal radio-ulnar joint. The *lateral surface* is narrow and presents a flat, semilunar facet for articulation with the scaphoid. The *medial surface* articulates with the triquetral and is almost square. It is separated from the distal surface by a curved ridge, which is usually somewhat hollowed out (fig. 406, A) for articulation with the edge of the wedge-shaped hamate bone (fig. 402), when the hand is adducted. The *distal surface* is deeply concave to accommodate the medial part of the head of the capitate bone.

THE TRIQUETRAL BONE

The **triquetral bone** (fig. 408), usually pyramidal in shape, is distinguished by an oval, isolated, smooth facet for articulation with the pisiform, which marks the distal part of its rough, *palmar surface*. The *medial and dorsal surfaces* are confluent. Rough distally for the attachment of the ulnar collateral ligament of the wrist-joint,

FIG. 408.—The left triquetral bone.
Palmar aspect.



FIG. 409.—The left pisiform bone.
Dorsal aspect.



this aspect is smooth in its proximal part, which articulates with the articular disc of the distal radio-ulnar joint in full adduction of the hand. The *hamate surface*, directed laterally and distally, forms a concavo-convex area, broad proximally and narrow distally. The *lunate surface*, almost square, is directed proximally and laterally.

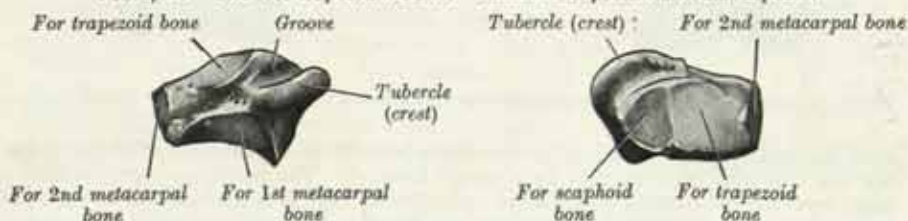
THE PISIFORM BONE

The **pisiform bone** (fig. 409), shaped like a pea with one flattened surface, can be distinguished by the fact that it possesses only one articular facet. This is on the *dorsal surface* of the bone to articulate with the triquetral, and its long axis runs distally and laterally. The non-articular part of the bone tends to project distally beyond the articular surface. The flexor carpi ulnaris is inserted on the palmar surface and its true continuation, viz., the pisometacarpal ligament, to the distal part of the bone. The flexor retinaculum is attached to the palmar part of the lateral aspect, while the abductor digiti minimi and the extensor retinaculum are attached to the medial aspect.

THE TRAPEZIUM BONE

The **trapezium bone** (fig. 410) can be identified by the tubercle and groove which mark its rough, *palmar surface*. The groove, which is medial to the tubercle, lodges the tendon of the flexor carpi radialis, and its margins give attachment to the two layers of the flexor retinaculum (fig. 613 and p. 640). The *tubercle* is obscured to a large extent by the origin of the muscles of the thenar eminence. The opponens pollicis arises

FIG. 410.—The left trapezium bone. Palmar and proximomedial aspects.



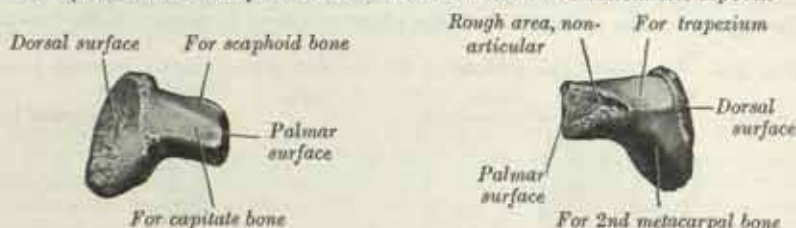
from its middle part, the flexor pollicis brevis from its distal part and the abductor pollicis brevis from its proximal part (fig. 403). The elongated, rough, *dorsal surface* is closely related to the radial artery, before it passes forwards into the palm to become the deep palmar arch. The *lateral surface* also is large and rough for the attachment of the radial collateral ligament of the wrist-joint and the capsular ligament of the carpometacarpal joint of the thumb. A large *saddle-shaped surface* is directed distally and laterally for articulation with the base of the metacarpal bone of the thumb. The

most distal part of the bone projects slightly between the bases of the first and second metacarpal bones and is covered with a small, quadrilateral facet which is directed distally and medially to articulate with the base of the second metacarpal bone. The medial surface is covered with a large, gently concave facet for articulation with the trapezoid bone. The proximal surface is occupied by a small, slightly hollowed-out facet, which articulates with the scaphoid bone.

THE TRAPEZOID BONE

The **trapezoid bone** (fig. 411) is small and very irregular in shape. The *palmar surface* is rough, narrow and considerably smaller than the rough, *dorsal surface*. It is continued for a short distance on to the lateral aspect. The *distal surface* articulates with the grooved base of the second metacarpal bone. Triangular in outline, it is

FIG. 411.—The left trapezoid bone. Proximomedial and distolateral aspects.

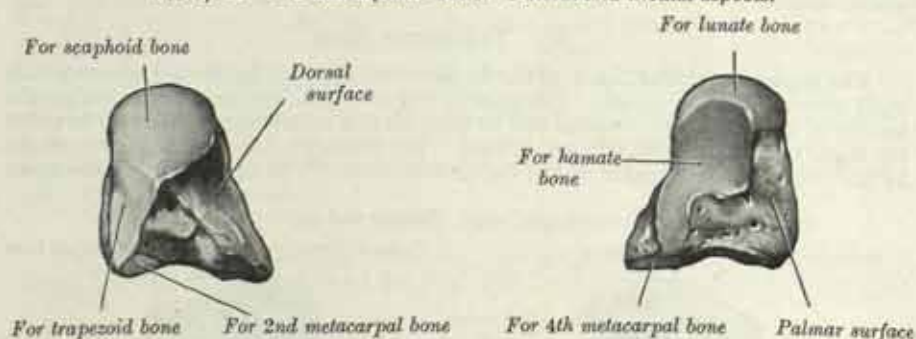


convex from side to side and concave from before backwards. The *medial surface* articulates with the distal part of the capitate bone, by means of a slightly concave facet. The *lateral surface* articulates with the trapezium, and the *proximal surface* with the scaphoid bone.

THE CAPITATE BONE

The **capitate bone** (fig. 412) is the largest of the carpal bones and lies opposite the base of the third metacarpal bone; it is therefore more or less central in position. The *distal surface* is roughly triangular and forms a concavoconvex facet for articulation with the base of the third metacarpal bone. Its lateral border is marked by a concave strip which articulates with the medial side of the base of the second metacarpal bone, and its dorso-medial angle usually bears a small facet for the fourth metacarpal bone. The convex *head* is received into the concavity formed by the lunate and scaphoid bones. Its *proximal surface* articulates with the lunate and its *lateral surface* with the scaphoid. The facet for the scaphoid is usually continuous

FIG. 412.—The left capitate bone. Lateral and medial aspects.



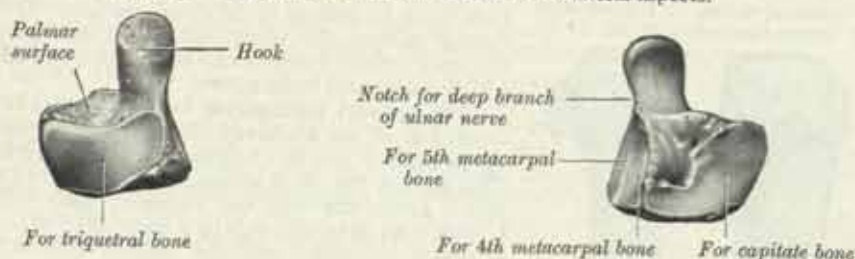
with the facet for the trapezoid on the distal part of the lateral surface of the bone, but the two may be separated by a rough interval. The *medial surface* presents a large facet for the hamate bone, deeper proximally than it is distally where a part of the surface is non-articular. The *palmar* and *dorsal surfaces* are roughened; the dorsal is the larger.

THE HAMATE BONE

The **hamate bone** (fig. 413) can be identified easily by its wedge-shaped form and the hook-like process which projects from the distal part of its rough, *palmar surface*. The concavity of the *hook* is directed to the lateral side, and takes part in the formation of the carpal canal. Its tip gives attachment to the flexor retinaculum. The distal

aspect of the base of the hook occasionally shows a slight transverse groove for the deep, terminal, branch of the ulnar nerve. The rest of the *palmar surface*, like the *dorsal surface*, is rough for the attachment of ligaments. The *distal surface* is divided

FIG. 413.—The left hamate bone. Medial and lateral aspects.



into two articular surfaces by a faint ridge: of these, the smaller, lateral facet articulates with the base of the fourth, and the larger, medial facet with the base of the fifth metacarpal bone. The *proximal surface* is the cutting edge of the wedge and usually bears a narrow facet which comes into contact with the lunate bone when the hand is adducted. The *medial surface* is covered by a broad articular strip, convex proximally and concave distally, for the triquetral bone. The *lateral surface* articulates with the capitate bone by means of a facet which covers all but the *disto-palmar* part of the surface.

THE METACARPUS

General features.—The **metacarpus** (figs. 402–405) comprises five metacarpal bones, which are numbered from the lateral to the medial side. They are miniature long bones, and each possesses a rounded head, a shaft and an expanded base. The *head* is at the distal end of the bone and articulates with the proximal phalanx. Its oblong, articular surface is convex, the degree of convexity being less in the transverse than in the anteroposterior direction, and extends farther proximally on the palmar surface than on the dorsal surface. The prominence of the knuckles is produced by the heads of the metacarpal bones. The *bases* of the metacarpal bones are formed by their expanded proximal ends, which articulate with the distal row of the carpus and with one another—save that the first metacarpal bone is isolated from the rest and does *not* articulate with the metacarpal bone of the index. The *shafts* are concave longitudinally on their palmar surfaces, an arrangement which provides a hollow for the lodgment of the muscles of the palm. The dorsal surface of each presents a flattened triangular area in its distal part, continued proximally as a rounded ridge. These flattened areas can be felt on the back of the hand in the living subject immediately proximal to the knuckles.

It should be observed that, whereas the medial four metacarpal bones lie side by side, the first metacarpal bone lies on a more anterior plane and that it is rotated medially round its long axis through an angle of 90° . As a result of this rotation its morphologically dorsal surface is directed to the lateral side, its radial border forwards, its palmar surface medially, and its ulnar border dorsally. By virtue of its position the thumb moves medially in front of the palm when it is flexed and it can be opposed to each of the fingers in turn. The ability to oppose the thumb to the fingers is rendered possible by the rotation of the bone medially. It is the most important factor in rendering the hand an efficient instrument for prehension, for, when an object is grasped in the hand, the fingers encircle it from one side and the thumb from the other, and the power of the grip is increased very greatly thereby.

THE CHARACTERS OF THE INDIVIDUAL METACARPAL BONES

The **first metacarpal bone** (fig. 414) is shorter and stouter than any of the others. Its dorsal surface faces laterally, a fact which can easily be confirmed in the living hand, and its long axis passes distally and laterally, diverging from its neighbour. The *shaft* is flattened and its dorsal surface is uniformly broad and convex from side to side. The palmar surface is concave in its long axis and is subdivided by a rounded ridge into a larger lateral and a smaller medial part. The *opponens pollicis* is inserted into the radial border and the adjoining part of the palmar surface; the radial head of the first dorsal interosseous muscle arises from the ulnar border and the adjoining part

of the palmar surface. The *base* presents a concavoconvex surface for articulation with the trapezium. On its lateral side it receives the insertion of the abductor pollicis longus; its ulnar side gives origin to the first palmar interosseous muscle (p. 651). The

FIG. 414.—The first right metacarpal bone. Palmar and lateral aspects.



head is less convex than the heads of the other metacarpal bones, and is broader from side to side than from its palmar to its dorsal surface. On its palmar surface the ulnar and radial corners are enlarged to form two articular eminences, on each of which a sesamoid bone glides.

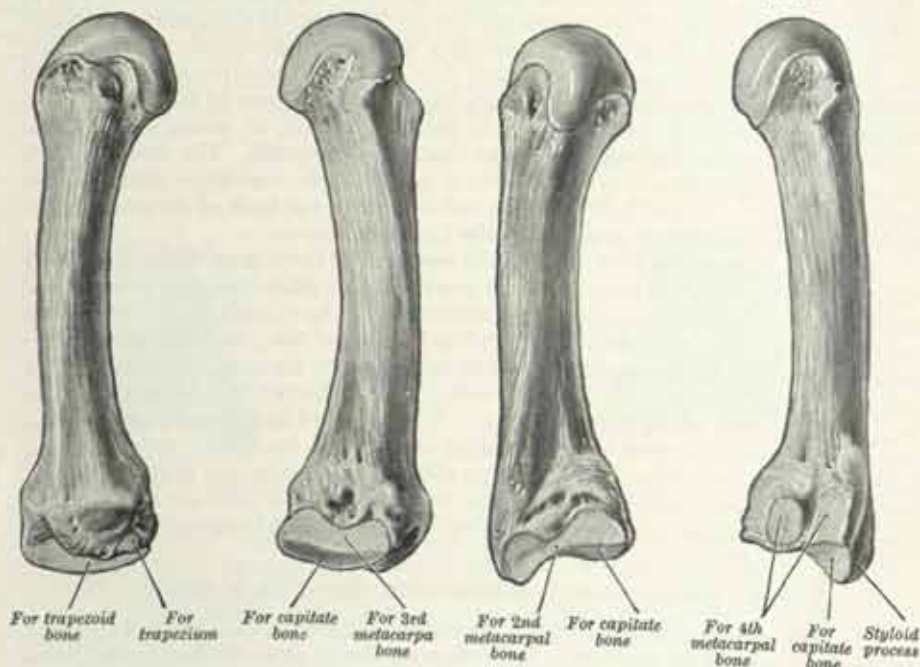
The **second metacarpal bone** (fig. 415) is the longest of all the metacarpal bones, and its base is the largest. It can be identified by its grooved *base*. This groove (fig. 613) is concave from side to side and it articulates with the trapezoid bone. It is bounded on its medial side by a deep ridge, the edge of which articulates with the capitate bone. The lateral side of the base is marked, nearer the dorsal than the palmar surface, by a small, quadrilateral facet for the trapezium. Immediately behind this facet, i.e. on the lateral part of the dorsal surface of the base, a small rough impression gives insertion to the extensor carpi radialis longus muscle. The palmar surface provides a small tubercle or ridge for the insertion of the flexor carpi radialis. The medial side of the base articulates with the lateral side of the

base of the third metacarpal bone by a strip-like facet, which is constricted at its middle.

The *shaft* is prismoid in form and curved so as to be convex dorsally in its long axis and concave towards the palm. It has medial, lateral and dorsal surfaces. The dorsal surface is broad near the head but narrows into a ridge as it approaches the base. This surface is covered by the extensor tendons of the index finger, and its converging borders commence in two little tubercles, which are situated one on each side

FIG. 415.—The left second metacarpal bone. Dorsolateral and medial aspects.

FIG. 416.—The left third metacarpal bone. Lateral and medial aspects.



of its head. The *lateral surface* inclines dorsally at its proximal end: it gives origin to the lateral head of the first dorsal interosseous muscle. The *medial surface* also inclines dorsally at its proximal end and is divided into two nearly parallel strips by a faint ridge. Of these, the more palmar gives origin to the second palmar interosseous and the more dorsal to the radial head of the second dorsal interosseous muscle.

The tubercles at the side of the head provide attachment for the collateral ligaments of the metacarpophalangeal joint.

The **third metacarpal bone** (fig. 416) can be identified by means of the short *styloid process*, which projects in a proximal direction from the radial side of the dorsal surface of its base. The *base* articulates, proximally, with the capitate bone by means of a facet which is convex in its palmar portion but concave in its dorsal portion, where it covers the styloid process. The lateral aspect of the base is marked by a strip-like facet, constricted at its middle, for articulation with the metacarpal bone of the index. On its medial side it articulates with the base of the fourth metacarpal bone by means of two small, discrete oval facets. Sometimes the more palmar facet is absent, and less frequently the two may be connected by a narrow bridge along the medial border of the base. The palmar surface of the base receives a slip from the flexor carpi radialis tendon, while its dorsal surface, immediately beyond the styloid process, gives insertion to the extensor carpi radialis brevis.

The *shaft* resembles the shaft of the metacarpal bone of the index. Its lateral surface gives origin to the ulnar head of the second dorsal interosseous and its medial surface to the radial head of the third dorsal interosseous muscle. The palmar ridge which separates these two surfaces gives origin, in its distal two-thirds, to the transverse head of the adductor pollicis. Its dorsal surface is covered by the extensor tendon of the middle finger.

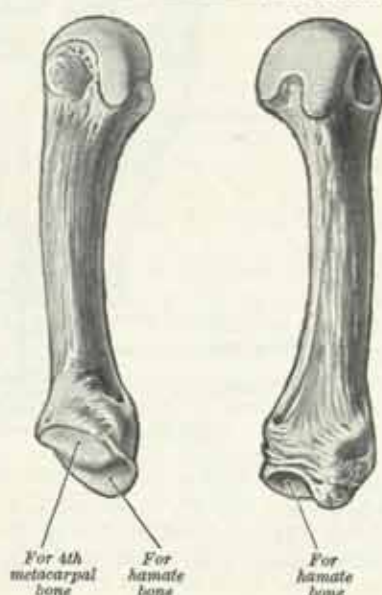
The **fourth metacarpal bone** (fig. 417) is shorter and more slender than the second and third metacarpal bones. It can be identified by examination of the sides of its *base*. The lateral aspect bears two small, oval, discrete facets for articulation with the third metacarpal bone. Of these the more dorsal is usually (but not always) the larger, and its proximal part comes into contact with the capitate bone. The medial aspect is marked by a single elongated facet for the fifth metacarpal bone. The proximal surface articulates with the hamate bone by a quadrangular facet, the palmar aspect of which is convex and the dorsal concave.

The *shaft* resembles the shaft of the metacarpal bone of the index finger, but its lateral surface is traversed by a faint ridge, which separates the origin of the third palmar interosseous from the origin of the ulnar head of the third dorsal interosseous

FIG. 417.—The left fourth metacarpal bone. Lateral and medial aspects.



FIG. 418.—The left fifth metacarpal bone. Lateral and medial aspects.



muscle. The medial surface gives origin to the radial head of the fourth dorsal interosseous muscle.

The **fifth metacarpal bone** (fig. 418) can be identified by the fact that the medial surface of the *base* is non-articular and presents a tubercle for the insertion of the extensor carpi ulnaris. The proximal surface of the base is covered by a facet, concave from side to side and convex from its palmar to its dorsal aspect, for articulation with the hamate bone. Its lateral aspect presents an elongated strip-like facet for the fourth metacarpal bone.

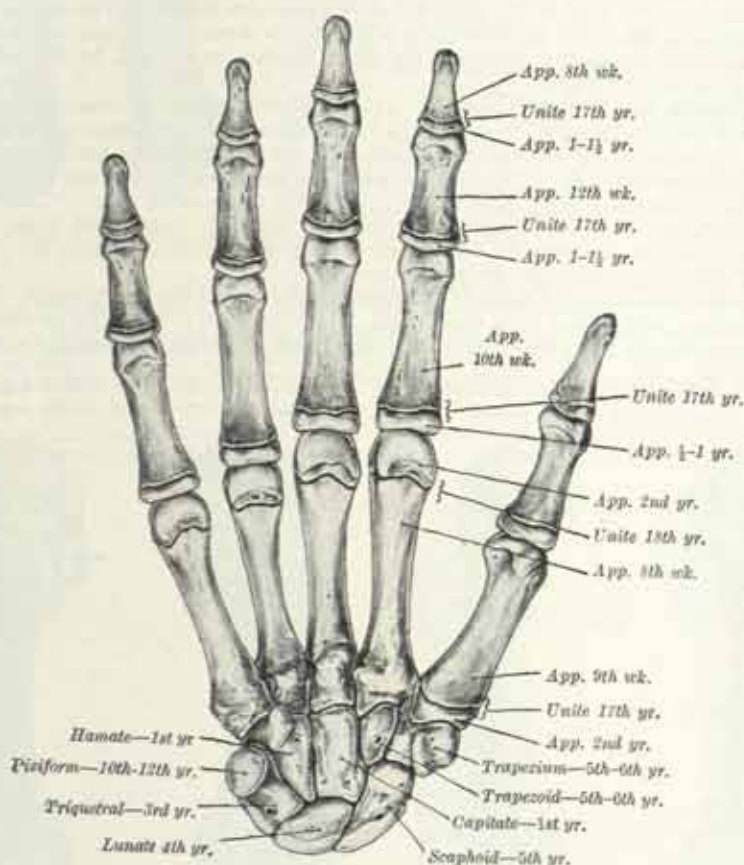
The *shaft* is characterised by the fact that the triangular area on its dorsal surface reaches almost to the base and that only the lateral surface inclines dorsally at its

proximal end. The medial surface gives insertion to the *opponens digiti minimi*; the lateral surface is divided by a longitudinal ridge, sometimes quite sharp and distinct, into a palmar strip for the origin of the fourth palmar interosseous, and a dorsal strip for the origin of the ulnar head of the fourth dorsal interosseous muscle.

THE PHALANGES OF THE HAND

General features.—The **phalanges** are fourteen in number, three for each finger and two for the thumb. Each has a head, a shaft and a base or proximal end. In each the *shaft* tapers to its distal end and its dorsal surface is convex from side to side. The palmar surface is flattened from side to side, but is gently concave forwards in its long axis. The *bases* of the proximal phalanges are marked by concave, oval facets for articulation with the heads of the metacarpal bones. Their *heads* are pulley-shaped

FIG. 419.—The bones of the hand of a child, indicating the general plan of ossification.



and encroach farther on the palmar than on the dorsal surfaces. To conform to the shape of the head of the proximal phalanx, the base of a middle phalanx is marked by two small, concave facets separated by a smooth ridge. The head of the middle phalanx also is pulley-shaped and the base of the distal phalanx conforms to it. The head of the distal phalanx is non-articular, but is marked on its palmar surface by a rough, horseshoe-shaped *tuberosity*, which serves to support the sensitive pulp of the finger-tip.

Particular features.—In addition to providing attachment for the ligaments of the joints in which they participate, the phalanges give insertion to numerous muscles. The base of the distal phalanx gives attachment on its palmar surface to the corresponding tendon of the *flexor digitorum profundus* and on its dorsal surface to the *extensor digitorum*. The sides of the middle phalanx receive the insertion of the *flexor digitorum superficialis* tendon (p. 629) and the *fibrous flexor sheath*. Its base gives attachment on its dorsal surface to a part of the *extensor digitorum* tendon. The sides of the proximal phalanx give attachment to the *fibrous flexor sheath*. Its base receives,

on its lateral side, part of the insertion of the corresponding *lumbrical muscle* and an *interosseous muscle*, and on its medial side another *interosseous muscle*.

The phalanges of the *little finger* and the *thumb* differ in certain respects from the other three. The medial side of the base of the proximal phalanx of the little finger receives the insertion of the *abductor digiti minimi* and the *flexor digiti minimi*. The base of the proximal phalanx of the thumb receives on its dorsal surface the tendon of the *extensor pollicis brevis*; on its lateral side the *abductor pollicis brevis*, the *flexor pollicis brevis* and the lateral part of the *oblique head* of the *adductor pollicis*; and, on its medial side, the *transverse* and the remainder of the *oblique head* of the *adductor pollicis* and the *first palmar interosseous muscle*. The margins of the proximal phalanx of the thumb are not sharp like those of the other digits, as the fibrous sheath is not so strongly developed in the case of the thumb.

THE OSSIFICATION OF THE BONES OF THE HAND

The centre for the capitate bone, which may be present at birth in the female, is the first to appear and that for the pisiform bone is the last, but the order in which the other carpal bones ossify is subject to considerable variation. In the male, the capitate and the hamate ossify during the first year; the triquetral bone, during the third year; the lunate bone, during the fourth year; the scaphoid bone, during the fifth year; the trapezoid and the trapezium, between the fifth and sixth years, the centre for the trapezoid usually appearing before the centre for the trapezium*; and the pisiform bone, about the twelfth year.

Occasionally an additional bone, named the *os centrale* (p. 443), is found between the scaphoid, trapezoid and capitate bones. During the second month of intra-uterine life it is represented by a small cartilaginous nodule which usually fuses with the cartilaginous scaphoid. Sometimes the styloid process of the third metacarpal bone is detached and forms an additional ossicle.

The **metacarpal bones** are each ossified from two centres: a primary centre for the shaft, and a secondary or epiphysal centre for the base or proximal end of the first and for the head or distal end of each of the other four. The metacarpal bone of the thumb is ossified like a phalanx, and therefore some anatomists look upon the skeleton of the thumb as consisting of three phalanges, and not of a metacarpal bone and two phalanges; others believe that the distal phalanx represents fused middle and distal phalanges, a condition which has occasionally been observed in the little toe.† Ossification begins in the middle of the shaft about the eighth or ninth week of intrauterine life, the centres for the second and third metacarpal bones being the first to appear, and that for the first metacarpal bone the last. Between the ninth and the fifteenth months the base of the first metacarpal bone, and the heads of the other metacarpal bones, begin to ossify; they unite with the shafts before the eighteenth year.

It has been suggested (Parsons) that the presence of an epiphysis only at the distal end of a typical metacarpal may be associated with the greater range of movement which the metacarpophalangeal joint enjoys. In the thumb, on the other hand, it is the carpometacarpal joint which possesses the wider range of movement, and the presence of a basal epiphysis in the first metacarpal bone may be attributable to this fact.‡ Occasionally a distal epiphysis also is present in the first, and a basal or proximal epiphysis sometimes occurs in the second metacarpal.

The **phalanges** are each ossified from two centres; a primary centre for the shaft, and a secondary or epiphysal centre for the proximal extremity. Ossification begins in the shaft about the eighth week of intrauterine life. The epiphyses for the bases of the proximal row of phalanges appear between six and twelve months, and those for the middle and distal rows of phalanges six months later. All unite with the shafts by the seventeenth year.

* J. W. Pryor, *J. Anat.*, 62, 1928.

† Broom (*Origin of the Human Skeleton*, Witherby, London, 1930) has put forward an ingenious explanation for the peculiar mode of ossification of the metacarpal bone of the thumb. His theory has, however, been subjected to serious criticism by Nicholson ("Studies on Tumour Formation," *Guy's Hospital Reports*, vol. 87, No. 1, 1937), who has brought forward evidence to show that, when the thumb possesses an additional phalanx, the condition is always associated with the presence of a distal as well as a proximal epiphysis for its metacarpal bone. The metacarpal bone of the thumb sometimes bifurcates at its distal end. In these cases the medial branch, which has a distal epiphysis, bears a digit with three phalanges, while the lateral branch, which has no distal epiphysis, bears a digit with two phalanges.

In the distal phalanges the centres for the shafts appear at the distal ends instead of at the middle of the shafts, as in the other phalanges. Moreover, of all the bones of the hand, the distal phalanges are the first to ossify, and the middle phalanges the last.

Applied Anatomy.—The use of X-rays has shown that the carpal bones are more frequently fractured than was formerly supposed. When a single bone is broken it is usually the scaphoid and, as a rule, the fracture runs at right angles to the long axis of the bone. Following fracture through its proximal part or through the 'waist' of the bone, non-union is by no means uncommon and may, in some cases, be due to the fact that the proximal fragment, which is devoid of nutrient foramina in 13 per cent. of cases (p. 384), has been cut off from its blood-supply.

Dislocation forwards of the lunate bone is not uncommon and it is often associated with fracture of the scaphoid.* The displaced lunate bone may compress the median nerve against the flexor retinaculum.

THE BONES OF THE LOWER LIMB

THE HIP-BONE [OS COXÆ]

General features.—The **hip-bone** (figs. 420-423) is a large, irregularly shaped bone, constricted in the middle and expanded above and below. Its *lateral surface* is marked near its middle by a deep, cup-shaped hollow, termed the **acetabulum**, which forms a secure socket for the rounded head of the femur. *Below and in front of* the acetabulum the bone presents a large, oval, or triangular, gap, termed the **obturator foramen**. *Above* the acetabulum the bone forms a wide, flattened plate, with a long, curved upper border termed the **iliac crest**. With this information the student should have no difficulty in assigning a given hip-bone to its appropriate side of the body.

The hip-bone articulates in front with the corresponding bone of the opposite side and the two bones form the pelvic girdles of the lower limbs (p. 356). Each consists of three parts, named the ilium, the ischium and the pubis, which are connected by cartilage in the young subject but are united by bone in the adult; the union of the three parts takes place in the walls of the acetabulum. The lines of fusion are shown as stippled bands in figs. 421 and 423. The *ilium* includes the upper part of the acetabulum and the expanded, flattened area of bone above it; the *ischium* includes the lower part of the acetabulum and the bone below and behind; the *pubis* forms the anterior part of the acetabulum and separates the ilium from the ischium in this situation; in addition, it forms the anterior part of the lower portion of the hip-bone and meets the pubis of the opposite side in the median plane.

The ilium.—**General features.** The ilium, so named because it supports the flank, possesses two ends and three surfaces. The lower end is the smaller and forms rather less than the upper two-fifths of the articular surface of the acetabulum; the upper end is greatly expanded and compressed to form the *iliac crest*. The surfaces are named the *gluteal surface*, the *sacropelvic surface* and the *iliac fossa*. The *gluteal surface* is directed backwards and laterally and forms an extensive rough area; the *iliac fossa* is smooth and gently hollowed out and occupies the anterior and upper part of the medial aspect of the ilium; the *sacropelvic surface* also is placed on the medial aspect and lies behind and below the iliac fossa, separated from it by a ridge, often termed the *medial border*.

The *iliac crest* constitutes an upper border for the ilium. It is convex upwards in its general outline, but is sinuously curved, being concave inwards in front and concave outwards behind. Its anterior and posterior extremities project a little beyond the bone below and are termed respectively the anterior and the posterior superior iliac spines. The *anterior superior spine* lies at the lateral end of the fold of the groin and can be felt without difficulty in the living subject; the *posterior superior spine* cannot be felt but it can be identified readily, because its position is indicated by a small dimple, which lies about 4 cm. lateral to the second spinous tubercle of the sacrum above the medial part of the buttock. Morphologically the crest consists of a long ventral and a shorter dorsal segment. The ventral segment forms rather more than the anterior two-thirds of the crest and is associated with alterations in the form of the ilium which were necessitated by the adoption of the erect attitude; the dorsal segment forms rather less than the posterior third of the crest and can be

* W. W. Gilford, R. H. Bolton and C. Lambrinudi, *Guy's Hosp., Rep.* 92, 1943.

PLATE XIII



FIG. 1.—Radiograph of an adult pelvis. The upper arrow indicates the line of the sacro-iliac joint; the lower arrow points to the upper border of the acetabulum. Note that the shadow of the curved upper border of the obturator foramen is in line with that of the lower border of the neck of the femur. Radiologists often refer to this continuous curve as 'Shenton's line'.



FIG. 2.—Radiograph of the pelvis of a boy, aged 6 years. The epiphysis for the head of the femur is well formed and the line of its epiphyseal cartilage is practically horizontal (p. 419). The centre for the greater trochanter has not yet appeared. The rami of the ischium and pubis are still connected by cartilage, and the triradiate cartilage of the acetabulum is wide.

PLATE XIV



Radiograph of the knee region of an adult. Lateral view.

identified in all animals. The ventral segment of the crest is bounded by an *outer* and an *inner line*, enclosing a rough *intermediate line*, which is narrowest at its middle and becomes wider both in front and behind. The *tubercle of the crest* (fig. 420) forms a prominent projection on the outer lip about 5 cm. or more behind and above the anterior superior spine. The dorsal segment presents two sloping surfaces separated by a well-marked ridge, which terminates in the posterior superior spine.

FIG. 420.—The left hip-bone. External surface.



The highest point of the crest, which is a little behind its midpoint, is on the same level as the interval between the spines of the third and fourth lumbar vertebræ.

The *lower end* of the ilium will be described with the acetabulum (p. 401).

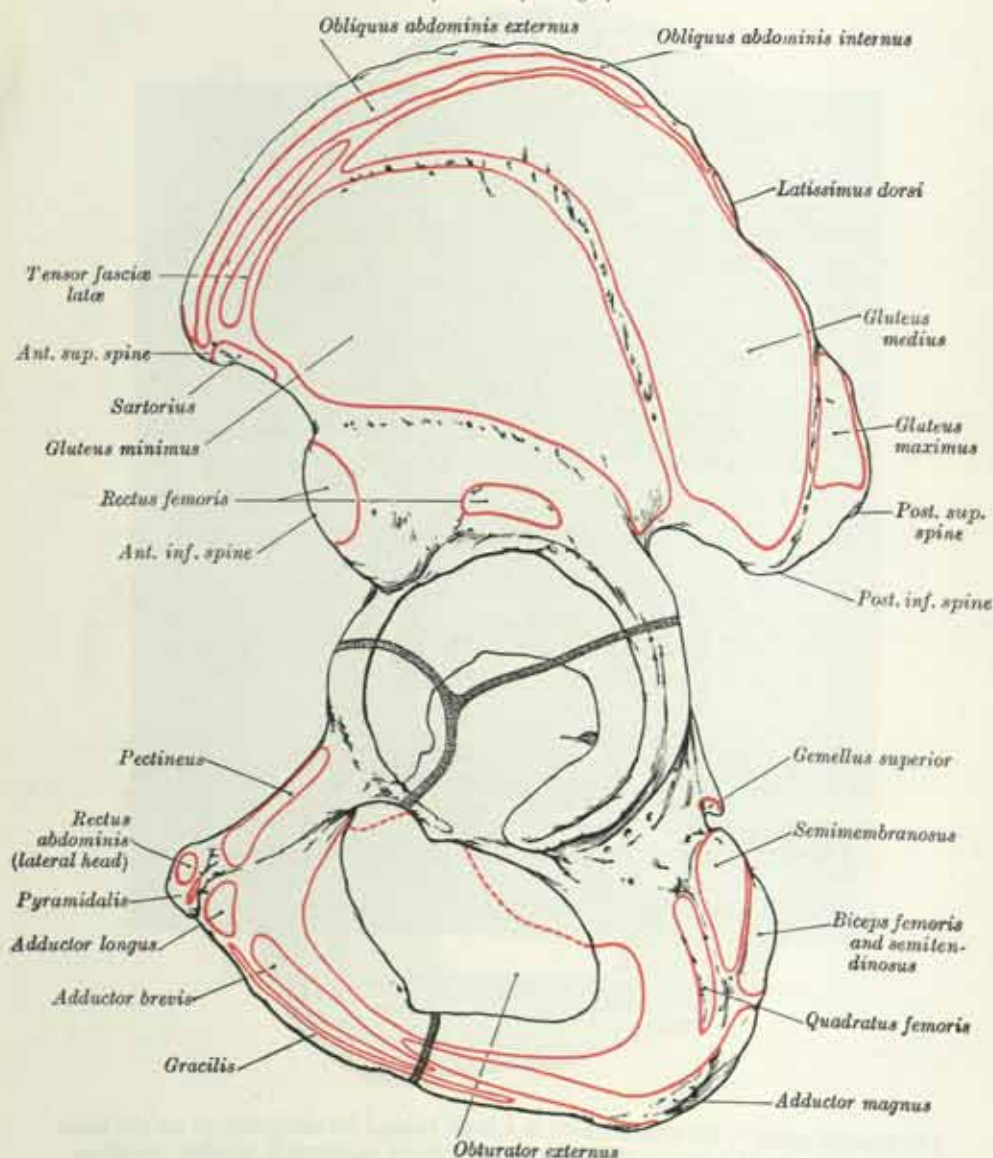
The *anterior border* of the ilium descends to the acetabulum from the anterior superior spine. Its upper part is rounded and concave forwards; its lower part presents a roughened projection, termed the *anterior inferior iliac spine*, which lies immediately above the anterior part of the acetabulum.

The *posterior border* is irregularly curved (fig. 423). It commences at the posterior superior spine and runs at first downwards and forwards, with a backward concavity, forming a small notch. At the lower end of the notch the bone presents a wide, low projection, termed the *posterior inferior spine*, where the posterior border makes a sharp bend. It then runs almost horizontally forwards for about 3 cm.

and finally turns downwards and backwards to become continuous with the posterior border of the ischium. As a result the posterior border shows a deep notch, termed the *greater sciatic notch*, which is bounded above by the ilium and below by the ilium and ischium (fig. 423).

The *medial border* is placed on the medial surface of the bone and separates the iliac fossa from the sacropelvic surface. Indistinct near the crest, it is roughened

FIG. 421.—Key to fig. 420.



Note.—For technical reasons, the area of the insertion of the obliquus abdominis externus is shown surrounded by a red line instead of a blue line, as in the other figures in this section.

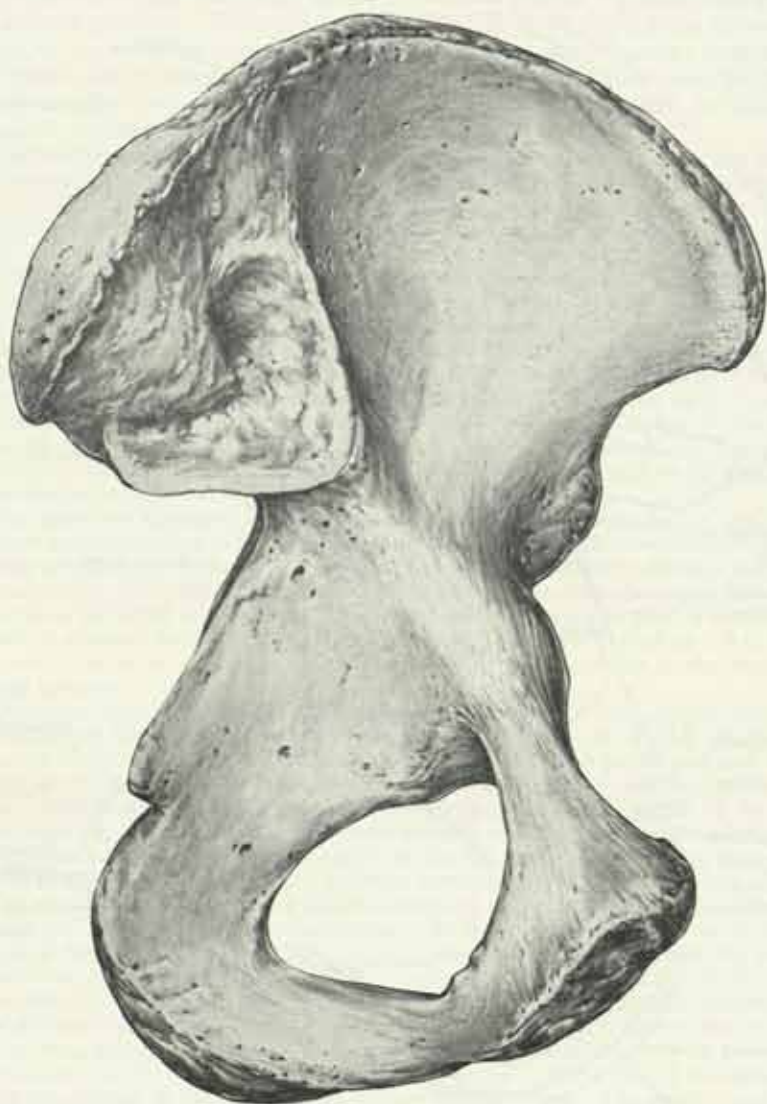
As explained in the text (p. 392) the stippled bands indicate the limits of the iliac, pubic and ischial parts of the bone.

in its upper part, then sharp and clear-cut where it bounds the articular surface for the sacrum, and finally smooth and rounded. The last-named portion forms the **iliac part of the linea terminalis**—the line that marks the boundary between the pelvis major and the pelvis minor; at its inferior end it reaches the posterior part of the *iliopectineal eminence*, which is placed at the union of the ilium with the pubis.

The *gluteal surface* (fig. 420) is directed backwards and laterally in its posterior

part, and laterally and slightly downwards in front. It is bounded above by the iliac crest, below by the upper border of the acetabulum and in front and behind by the anterior and posterior borders. The surface, as a whole, is smooth and curved, being convex in front and concave behind, but it is marked by three roughened ridges termed the posterior, middle and inferior gluteal lines. The *posterior gluteal line*, which is the shortest of the three, begins above on the outer lip of the crest

FIG. 422.—The left hip-bone. Internal surface.



about 5 cm. in front of its posterior extremity and ends below, a short distance in front of the posterior inferior spine. Its upper part is usually distinct, but its lower part is ill-defined and frequently absent. The *anterior gluteal line*, which is the longest of the three, begins about the middle of the upper margin of the greater sciatic notch and runs upwards and forwards to become confluent with the outer lip of the crest a little in front of the tubercle. The *inferior gluteal line*, which is rarely a prominent feature, begins a little above and behind the anterior inferior spine and curves backwards and downwards to end near the apex of the greater sciatic notch. Between the inferior gluteal line and the margin of the acetabulum there is a rough, shallow groove on the bone. Behind the acetabulum the lower part of the gluteal

the pelvic surface. The *iliac tuberosity* is an extensive, roughened, tuberculated and pitted area which lies immediately below the dorsal segment of the iliac crest. It gives attachment to the strong ligaments on the dorsal surface of the sacro-iliac joint. The *auricular surface* (fig. 422) is placed immediately below and in front of the tuberosity, and articulates with the lateral mass of the sacrum. It is shaped like the auricle—the wide expanded portion lying above and in front, and the lobule below and behind, covering the medial aspect of the posterior inferior spine. The edges are sharp and clearly defined, but the surface, although articular, is finely roughened and irregular. The *pelvic surface* lies below and in front of the auricular surface and helps to form the wall of the pelvis minor (true pelvis). It comprises an upper and a lower portion. The upper portion faces downwards and lies between the margin of the auricular surface and the upper border of the greater sciatic notch. The lower portion faces inwards and is separated from the iliac fossa by the iliac part of the linea terminalis. The line of union of the ilium with the ischium is completely obliterated on this surface.

Particular features.—The *iliac crest* forms the lower limit of the waist and gives attachment to the lateral muscles of the abdominal wall, to fasciæ and muscles of the lower limb and to muscles and fasciæ of the back (figs. 421, 423). The *outer lip* of the ventral segment (p. 392) gives attachment to the fascia lata, including the iliotibial tract; in front of the tubercle of the crest it gives origin to the tensor fasciæ latæ: in its anterior two-thirds it provides insertion for the lower fibres of the external oblique; and just behind its highest point it gives origin to the lowest fibres of the latissimus dorsi. An interval of variable size intervenes between the posterior limit of the insertion of the external oblique and the anterior limit of the origin of the latissimus dorsi; in this situation the crest forms the base of the lumbar triangle. The *intermediate line* gives origin to the internal oblique muscle. The *inner lip* in its anterior two-thirds gives origin to the transversus muscle; and behind that to the lumbar fascia and the quadratus lumborum muscle. The dorsal segment (p. 392) gives origin on its lateral slope to the highest fibres of the gluteus maximus, and on its medial slope to the erector spinæ muscle.

The *anterior superior spine* gives attachment to the lateral end of the inguinal ligament and below that to the sartorius muscle, which extends downwards for a short distance on the *anterior border*. The *anterior inferior spine* is divided indistinctly into two areas. The upper gives origin to the straight head of the rectus femoris and is placed on the front of the spine. The lower covers the inferior part of the spine and extends in a lateral direction along the upper margin of the acetabulum; it is a rough impression, irregularly triangular in shape, and gives attachment to the strong ilio-femoral ligament.

The upper part of the *posterior border* gives attachment to the upper fibres of the sacro-tuberosus ligament. In front of the posterior inferior spine (i.e. on the upper border of the greater sciatic notch), it gives origin to fibres of piriformis and, in front of that, is related to the superior gluteal vessels and nerve as they emerge from the pelvis. The lower part of the posterior border (i.e. the lower margin of the greater sciatic notch) is covered by the piriformis muscle and is related to the sciatic nerve, although the nerve lies for the most part on the ischium.

The *gluteal surface* is divided into four areas by the three gluteal lines (fig. 420). (a) The area behind the posterior gluteal line gives origin in its upper roughened part to the upper fibres of the gluteus maximus; its lower, smooth part gives attachment to some of the fibres of the sacrotuberosus ligament. (b) The area between the posterior and anterior gluteal lines, bounded above by the iliac crest, gives origin to the gluteus medius muscle. (c) The area between the anterior and inferior gluteal lines gives origin to the gluteus minimus muscle. (d) The area below the inferior gluteal line is marked by numerous vascular foramina. The groove above the acetabulum gives origin to the reflected head of the rectus femoris, and the area adjoining the rim of the acetabulum affords attachment to the articular capsule of the hip-joint. The greater part of this area is covered by the gluteus minimus muscle, but behind and below in the neighbourhood of the site of union of the ilium and ischium, the bone is related to the piriformis muscle.

The upper two-thirds of the *iliac fossa* provides origin for the iliacus muscle (fig. 423), which covers the lower third but is not attached to it. Branches of the ilio-lumbar artery run between the muscle and the bone, and one of them enters the large nutrient foramen which is often present at the postero-inferior part of the fossa. The groove between the anterior inferior spine and the iliopectineal eminence is occupied by the converging fibres of the iliacus muscle laterally and the tendon of psoas major medially; the tendon is separated from the bone near the acetabulum by its synovial bursa. On the right side the iliac fossa contains the cæcum and the terminal part of the ileum; on the left side it contains the terminal part of the descending colon.

The *iliac tuberosity* of the sacropelvic surface gives attachment to the dorsal

sacro-iliac ligaments and, immediately behind the auricular surface, to the interosseous sacro-iliac ligament. The upper and anterior part of the tuberosity gives attachment to the iliolumbar ligament, and this area lies immediately below the medial part of the origin of the quadratus lumborum from the iliac crest. The **auricular surface** articulates with the upper two and a half sacral vertebrae (two only, as a rule, in the female). Its anterior and inferior borders are sharp and give attachment to the ventral sacro-iliac ligament. The upper part of the **pelvic surface** between the inferior margin of the auricular surface and the upper margin of the greater sciatic notch is often marked in *female subjects* by a roughened groove, which is termed the *pre-auricular sulcus*; it gives attachment to the lower fibres of the ventral sacro-iliac ligament. Lateral to the sulcus the bone gives origin to fibres of the piriformis muscle. The rest of the pelvic surface gives origin to the upper half or less of the obturator internus muscle.

The pubis.—General features. The **pubis** forms the anterior part of the hip-bone and meets the pubis of the opposite side in the median plane to form a cartilaginous joint, termed the pubic symphysis. It possesses a body, which lies anteriorly; a superior ramus, which passes upwards and backwards to the acetabulum; and an inferior ramus, which passes backwards, downwards and laterally to unite with the ramus of the ischium on the medial side of the obturator foramen.

The *body* is compressed from before backwards and presents anterior, posterior and symphyseal (or medial) surfaces and a free upper border termed the *pubic crest*. The *anterior surface* faces downwards, forwards and slightly laterally in the erect posture; rough in its upper and medial parts, it presents a smooth surface elsewhere. It is directed towards the lower limb and affords attachment for the medial group of muscles of the thigh. The *posterior surface* is smooth and faces upwards and backwards, forming the anterior wall of the pelvis minor; it is related to the urinary bladder. The *symphyseal surface* is an elongated oval area, covered with cartilage in the recent state and articulating with the opposite pubis at the pubic symphysis. When denuded of cartilage it presents an irregular surface, marked by a number of small ridges and furrows or by small nodular elevations. The *pubic crest* is the rounded upper border of the body. It is projected forwards and overhangs the upper part of the anterior surface (fig. 420). Its lateral extremity forms a rounded projection termed the *pubic tubercle*. Both the crest and the tubercle can be felt through the skin in the living subject, but the latter is obscured by the spermatic cord, which crosses its upper aspect as it passes upwards from the scrotum to pierce the abdominal wall.

The *superior ramus* of the pubis springs from the upper and lateral part of the body, and passes backwards, upwards and laterally above the obturator foramen to reach the acetabulum. It is triangular on section and has three surfaces and three borders. The *pectineal surface* is directed forwards and slightly upwards. Triangular in outline, it extends from the pubic tubercle to the iliopectineal eminence (fig. 420). It is bounded in front by a rounded ridge termed the *obturator crest*, and behind by a sharp edge termed the *pectineal line*, which together with the pubic crest constitutes the pubic part of the linea terminalis (arcuate line). The *pelvic surface*, which is directed upwards, backwards and medially, is smooth and featureless; it is narrower at its lateral than at its medial extremity, where it is continuous with the posterior surface of the body. It is bounded above by the pectineal line and below by a sharp edge which forms the *inferior border*. The *obturator surface* is directed downwards and backwards, and is crossed from behind forwards and downwards by a groove termed the *obturator groove*. It is bounded in front by the obturator crest and behind by the inferior border.

The *inferior ramus* springs from the lower and lateral part of the body and passes backwards, downwards and laterally to unite with the ramus of the ischium on the medial side of the obturator foramen. The site of union may be marked by a localised thickening, but is often difficult to identify in the adult bone. The ramus has two surfaces and two borders. The *anterior or outer surface* is continuous above with the anterior surface of the body; it is directed towards the thigh and is roughened for muscular attachments. It is bounded laterally by the margin of the obturator foramen and medially by a rough anterior border. The *posterior or inner surface* is continuous above with the posterior surface of the body, and is convex from side to side. Its medial part is often prominently everted in male subjects (fig. 430) and is in contact with the crus of the penis. It is directed medially towards the perineum. Its lateral part is smooth and is directed upwards towards the pelvis.

Particular features.—The **pubic tubercle** gives attachment to the medial end of

the inguinal ligament; it lies in the floor of the superficial inguinal ring and is crossed by the spermatic cord. The ascending limbs of the loops of the cremaster muscle are attached to the tubercle and to the anterior wall of the sheath of the rectus abdominis muscle. The lateral part of the **pubic crest** gives origin to the lateral head of the rectus abdominis, and the bone below to the pyramidalis. The medial part of the crest is crossed by the medial head of the rectus abdominis, which takes origin from an interlacement of fibres in front of the upper part of the pubis and pubic symphysis. The *anterior surface* of the body is directed towards the adductor region of the thigh. A roughened strip, usually wider in the female, marks the medial part of the surface and gives attachment to the ventral pubic ligament. In the angle between the upper end of this strip and the pubic crest the rounded tendon of the adductor longus takes origin. At a slightly lower level the gracilis arises from a linear origin close to the medial border of the body and extending downwards on to the inferior ramus. Lateral to the gracilis the adductor brevis arises from the body and the inferior ramus. The lateral part of the anterior surface, and the adjoining portions of both rami provide origin for the obturator externus muscle (fig. 421).

The **posterior surface** of the body is separated from the urinary bladder by the retropubic pad of fat. About its middle it provides origin for the anterior fibres of the levator ani muscle, and more laterally the obturator internus arises from this surface and extends on to both rami. Medial to the origin of the levator ani, the pubo-prostatic ligaments are attached to the bone.

The *pectineal surface* of the **superior ramus** gives origin, along its upper part, to the pectineus muscle, which covers the rest of the surface (fig. 421) but is not attached to it. The **pectineal line**, which forms the upper boundary of the pectineal surface, is a salient, sharp ridge. At its medial end it gives attachment to the conjoint tendon and the lacunar ligament, and throughout the rest of its extent it affords attachment to a strong fibrous band often termed the *pectineal ligament* (p. 592). About its middle it receives the insertion of the psoas minor. The *pelvic surface* is smooth and is not covered with muscle or fascia. It is separated from the parietal peritoneum only by the intervening subperitoneal tissue, in which the lateral umbilical ligament runs downwards and forwards across the ramus and, near its lateral end, the vas deferens passes backwards. The *obturator groove* on the obturator surface is converted into a canal by the upper borders of the obturator membrane, the obturator internus and the obturator externus muscles. It transmits the obturator vessels and nerve from the pelvis to the thigh, where they emerge under cover of the pectineus muscle. The *obturator crest* (fig. 421) at its lateral end gives attachment to some of the fibres of the pubofemoral ligament.

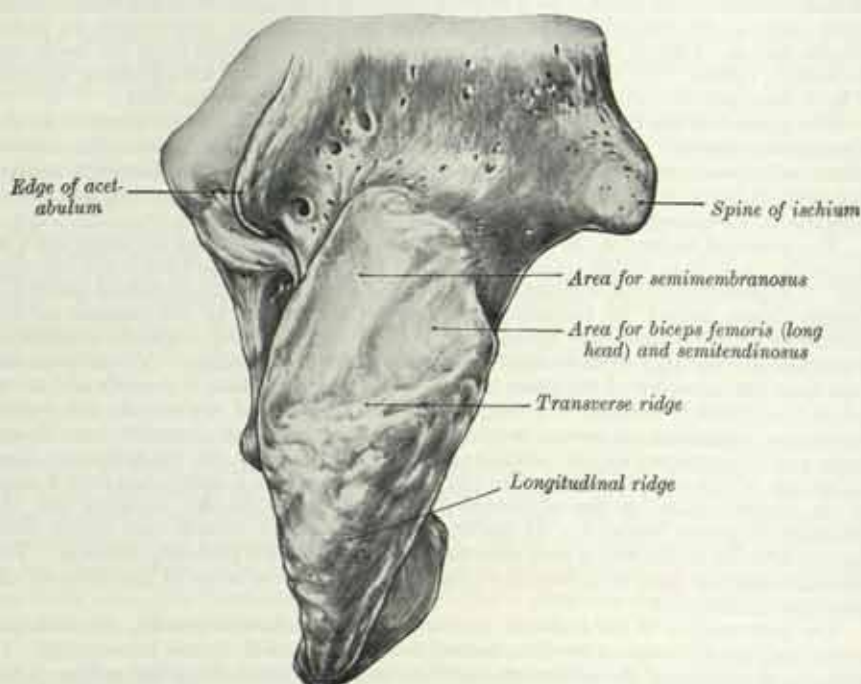
The *outer surface* of the **inferior ramus** gives origin to the gracilis, the adductor brevis and the obturator externus, named from the medial to the lateral side. In addition, the origin of the adductor magnus usually extends from the ramus of the ischium on to the lower part of the inferior ramus of the pubis in the interval between the adductor brevis and the obturator externus. The *inner surface* is divided into a medial, an intermediate and a lateral area, but they are not separated from one another by clear-cut markings on the bone. The medial area faces downwards and medially and is in direct contact with the crus penis; it is limited above and behind by an indistinct ridge which gives attachment to the perineal membrane (p. 609). The intermediate area is related to the dorsal nerve of the penis and the internal pudendal vessels and the fascial sheath in which they are enclosed, and it may give origin to some of the inner fibres of the sphincter urethrae muscle. The lateral area gives origin to fibres of the obturator internus muscle. The *medial margin* of the ramus is strongly everted in the male and gives attachment to the fascia lata and to the membranous layer of the superficial fascia of the perineum.

The ischium.—General features.—The **ischium** forms the lower and posterior part of the hip-bone. It comprises a body and a ramus. The body has upper and lower extremities, and femoral, dorsal and pelvic surfaces. The *upper extremity* of the body forms the lower and posterior part of the acetabulum, and its *lower extremity* gives off the *ramus*, which runs upwards, forwards and medially at an acute angle to fuse with the descending ramus of the pubis, so completing the obturator foramen.

The *femoral surface* of the body faces downwards, forwards and laterally towards the thigh. It is bounded in front by the margin of the obturator foramen, and laterally by the lateral border, which is indistinct above but clearly defined below, where it forms the lateral border of the ischial tuberosity. The *dorsal surface* faces backwards, laterally and upwards. Above, it is continuous with the lower part of the gluteal surface of the ilium, and where the two elements meet, the bone presents a low convexity, which corresponds with the curvature of the posterior part of the acetabulum. Below, the surface is marked by the upper part of the ischial tuber-

osity. Above the tuberosity the bone presents a wide and shallow groove both on the lateral and on the medial side. The *ischial tuberosity* is a large, roughened impression which marks the lower part of the dorsal surface and the inferior extremity of the body of the ischium. Although obscured by the gluteus maximus muscle when the hip-joint is extended, it can be identified without difficulty when the joint is flexed. It lies 5 cm. from the median plane and about the same distance above the gluteal fold (p. 664). It is an elongated area, widest near its upper end and tapering inferiorly, and provides attachment for some of the largest muscles of

FIG. 424.—The left ischial tuberosity, viewed from behind and below.



The *transverse ridge* forms the lower boundary of the area for the hamstring muscles and separates it from the lower half of the tuberosity, which is divided into lateral and medial areas by the *longitudinal ridge*. The lateral area gives origin to the adductor magnus; the medial area is covered with fibro-fatty tissue and supports the body in the sitting posture.

the thigh. The dorsal surface is placed between the lateral and the posterior borders of the body. The *posterior border* is continuous above with the posterior border of the ilium and helps it to complete the lower margin of the greater sciatic notch. The posterior end of that margin is marked by a conspicuous projection, termed the *ischial spine*. Below the spine the border becomes rounded and indefinite, forming the floor of a rounded notch, termed the *lesser sciatic notch*, which lies between the ischial spine and the tuberosity. The *pelvic surface* is smooth and relatively featureless and is directed towards the pelvic cavity; its lower portion forms part of the lateral wall of the ischiorectal fossa in the perineum.

The *ramus* of the ischium presents anterior and posterior surfaces, continuous with the corresponding surfaces of the inferior pubic ramus. The *anterior surface* is directed forwards and downwards towards the thigh and is rough for the attachment of the medial femoral muscles. The *posterior surface* is smooth, and partly subdivided into a perineal and a pelvic area, like the inferior ramus of the pubis. The *upper border* helps to complete the margin of the obturator foramen; the *lower border* is roughened and free, and together with the medial border of the inferior ramus of the pubis forms the lateral boundary of the subpubic angle and part of the pubic arch.

Particular features.—The *femoral surface* of the **body of the ischium** gives origin below to a part of the obturator externus muscle (fig. 421), and along the lateral border of the upper part of the ischial tuberosity to the quadratus femoris. Just below the acetabulum the lateral border gives attachment to the ischiofemoral ligament.

Immediately above the ischial tuberosity the *dorsal surface* is crossed by the tendon of the obturator internus and the gemelli muscles; the nerve to the quadratus femoris runs downwards between these structures and the bone. At a higher level, the bone is covered with the piriformis muscle, which is partially separated from it by the sciatic nerve and the nerve to the quadratus femoris. The **ischial tuberosity** is divided by a nearly transverse ridge into an upper and a lower area (fig. 424). The upper area is associated with the hamstring muscles; it is divided by an oblique line into an upper and lateral part which gives origin to the semimembranosus, and a lower and medial part from which the long head of the biceps femoris arises in common with the semitendinosus muscle. The lower portion of the tuberosity narrows as it passes forwards on to the lower end of the ischium. It is divided into a lateral and a medial area; the lateral area is the larger and affords origin to part of the adductor magnus muscle; the medial area is covered by fibro-fatty tissue, which usually contains the ischial bursa of the gluteus maximus. It is the medial area on the lower part of the tuberosity which supports the body in the sitting posture. On its medial side the tuberosity is limited by a curved ridge which extends forwards on to the ramus of the ischium and gives attachment to the sacrotuberal ligament and its falciform process (fig. 423). Many of the fibres of origin of the biceps femoris can be traced into the sacrotuberal ligament, and this intimate relationship is noteworthy, for the sacrum and the posterior part of the ilium constitute the primitive mammalian origin of the biceps femoris. The origin of the muscle from the tuberosity in man is secondary and the sacrotuberal ligament represents the remains of its primitive tendon of origin.

Above and medial to the tuberosity the posterior surface presents a wide, shallow groove. In this situation the bone is usually covered with a thin layer of cartilage in the recent state and a bursa is interposed between it and the tendon of the obturator internus, which lies in the groove. The lower margin of the groove, close to the tuberosity, gives origin to the inferior gemellus; the upper margin of the groove close to the ischial spine, gives origin to the superior gemellus.

The **ischial spine** projects downwards and slightly medially. Its margins give attachment to the sacrospinal ligament, which separates the greater sciatic foramen from the lesser (fig. 521). Its dorsal surface is crossed by the internal pudendal vessels and the nerve to obturator internus, as they lie in the gluteal region. The pelvic surface of the spine gives origin to the coccygeus and the most posterior fibres of the levator ani muscle. The structures transmitted by the greater and lesser sciatic foramina are detailed on p. 508.

The *pelvic surface* of the body of the ischium is smooth. Its upper part gives origin to the obturator internus muscle, the fibres of which converge on the lesser sciatic notch and cover the remainder of this surface, with the exception of the pelvic aspect of the ischial spine. The muscle and its covering fascia separate the bone from the ischiorectal fossa.

The *anterior surface* of the **ramus of the ischium** is directed towards the adductor region of the thigh. It gives origin to the obturator externus above, the anterior fibres of the adductor magnus and, near the lower border, to the gracilis muscle. Between the adductor magnus and the gracilis the origin of the adductor brevis may extend downwards from the inferior ramus of the pubis for a short distance. The *posterior surface* is divided into pelvic and perineal areas. The pelvic area is directed upwards and backwards and gives origin to part of the obturator internus. The perineal area is directed medially; its upper part is related to the crus of the penis and gives origin to the sphincter urethrae; its lower part gives origin to the ischiocavernosus and to the superficial transversus perinei muscle. The perineal membrane is attached to the ridge which separates the perineal from the pelvic area below, and the area for the crus from the origin of the sphincter urethrae above. The *lower border* of the ramus provides attachment for the fascia lata of the thigh and the membranous layer of the superficial fascia of the perineum.

The **acetabulum** (fig. 420) is a deep cup-shaped cavity on the lateral aspect of the hip-bone about its centre, and is directed laterally, downwards and forwards. It is surrounded by an irregular projecting margin which is deficient inferiorly; this gap is termed the *acetabular notch*. The floor of the cavity is roughened and non-articular and is termed the *acetabular fossa*. The sides of the cup present a horseshoe-shaped, articular, *lunate surface*, which is widest superiorly; in this situation the weight of the trunk is transmitted to the femur in the erect attitude. In the recent state this strip is covered with articular cartilage and provides the surface on which the head of the femur moves within the hip-joint. All three elements of the hip-bone contribute to the formation of the acetabulum in man, but not in equal proportions. The pubis forms the upper and anterior fifth of the articular surface; the ischium, the floor of the acetabular fossa and rather more

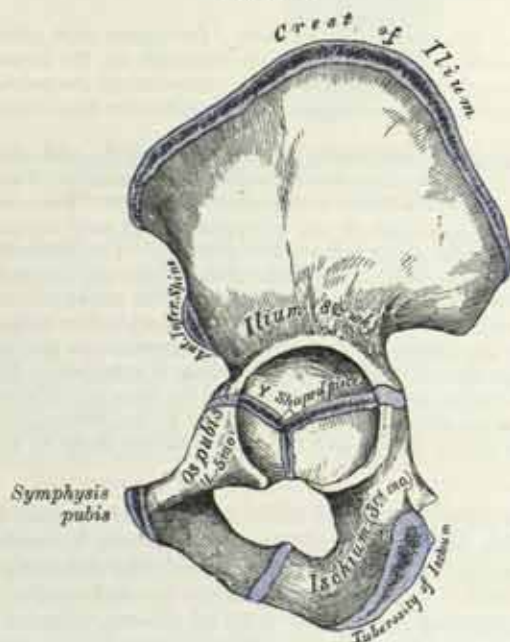
than the lower and posterior two fifths of the articular surface; the ilium forms the remainder of the articular surface.

The **obturator foramen** is a large gap in the hip-bone, below and slightly in front of the acetabulum and placed between the pubis and the ischium. It is bounded above by the grooved obturator surface of the superior ramus of the pubis; medially by the body and inferior ramus of the pubis; below by the ramus of the ischium; and laterally by the anterior border of the body of the ischium, including the margin of the acetabular notch. The foramen is occupied in the recent state by a fibrous sheet, termed the *obturator membrane*, which is attached to its margins except above, where a communication is left between the pelvis and the thigh. The free upper edge of the membrane is attached in front to the *anterior obturator tubercle*, which marks the anterior end of the inferior border of the superior ramus of the pubis, and behind to the *posterior obturator tubercle*, which is placed on the anterior border of the acetabular notch. These tubercles are not always easy to identify. The foramen is large and oval in the male, but is smaller and nearly triangular in the female.

Structure.—The thicker parts of the hip-bone consist of spongy substance, enclosed between two layers of compact bone; the thinner parts, as at the bottom of the acetabulum and centre of the iliac fossa, are usually semitransparent, and composed entirely of compact bone. At the upper part of the acetabulum and along the *linea terminalis* i.e. along the line of weight transmission from the sacrum to the head of the femur, the amount of compact bone shows a considerable increase. In this situation the underlying spongy substance shows the presence of two sets of pressure lamellæ. The first arise near the upper part of the auricular surface and diverge to impinge on two stout buttresses formed by the compact bone. From there two similar sets of lamellar arches take origin and converge on the acetabulum.*

Ossification (fig. 425).—The hip-bone is ossified from eight centres: three primary, one each for the ilium, ischium, and pubis; and five secondary, one each

FIG. 425.—A plan of the ossification of the hip-bone.



The three primary centres unite through the Y-shaped piece, about puberty. Secondary centres appear about puberty, and unite about 25th year.

centres extend their growth into the bottom of the acetabulum, where they are separated from each other by a Y-shaped portion of cartilage, which begins to

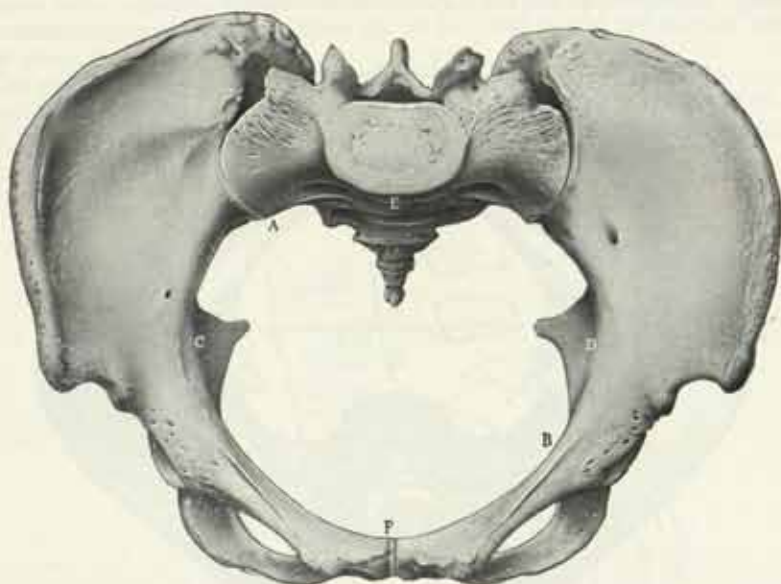
* C. P. G. Wakeley, *J. Anat.*, 64, 1929.

for the iliac crest, the anterior inferior iliac spine (said to occur more frequently in the male than in the female), the tuberosity of the ischium, the pubic symphysis (more frequent in the female than in the male), and one or more for the Y-shaped cartilage at the bottom of the acetabulum. The centres appear in the following order: in the ilium, immediately above the greater sciatic notch, about the eighth or ninth week of intrauterine life; in the body of the ischium, about the third month; in the superior ramus of the os pubis, between the fourth and fifth months. At birth, the iliac crest, the greater part of the acetabulum, the ischial tuberosity, and the inferior ramus of the pubis and the ramus of the ischium are cartilaginous. By the seventh or eighth year, the inferior ramus of the pubis and the ramus of the ischium are almost completely united by bone. The three primary

ossify from two or more centres in the twelfth year. One of these centres, named the *os acetabuli*, forms a triangular scale of bone over the acetabular part of the pubis and fuses with the main parts of the bone about puberty. The ilium and ischium then become joined, and lastly the pubis and ischium, through the medium of this Y-shaped portion. At about the age of puberty, ossification takes place in each of the remaining portions, and they join with the rest of the bone between the twentieth and twenty-fifth years. Separate centres are frequently found for the pubic tubercle, crest and angle, and for the ischial spine.

Comparison of the girdles of the upper and lower limbs.—The importance of mobility in the upper limb as contrasted with the necessity for stability in the lower limb is well illustrated by the more obvious differences which exist between the two girdles.

FIG. 426—The diameters of the inlet of the true pelvis in the female.



A=sacro-iliac joint; *B*=ilio-pubic eminence; *C* and *D*=middle of pelvic brim; *E*=sacral promontory and *F*=pubic symphysis.

Girdle of Upper Limb.

- (a) Consists of two separate bones, viz., the scapula and the clavicle.
- (b) Reaches the axial skeleton only at the sternoclavicular joint.
- (c) Is not directly connected to its fellow of the opposite side, except by the interclavicular ligament.
- (d) Has a shallow fossa for the head of the humerus.

Girdle of Lower Limb.

- (a) Consists of a single bone, viz., the hip-bone.
- (b) Articulates with the vertebral column at the sacro-iliac joint.
- (c) Articulates with its fellow of the opposite side at the pubic symphysis.
- (d) Has a deep cup for the head of the femur.

THE PELVIS

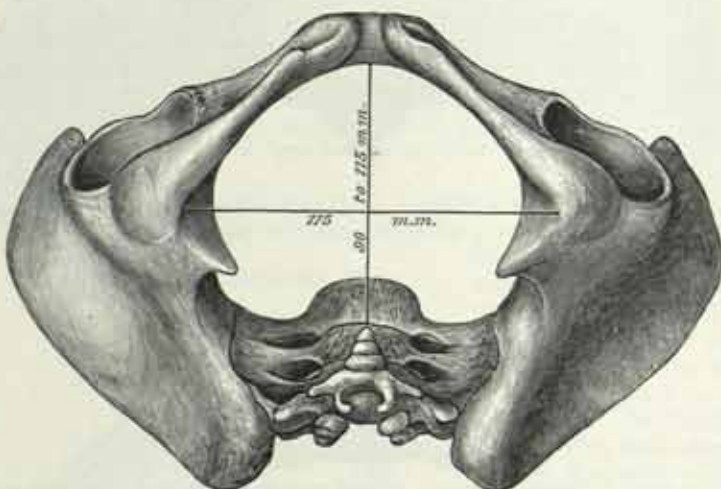
The **pelvis**, so called from its resemblance to a basin, is a massive bony ring interposed between the movable segments of the vertebral column, which it supports, and the lower limbs, upon which it rests; it is composed of the two hip-bones laterally and in front, and the sacrum and coccyx behind. It is divided into the greater (false) and the lesser (true) pelvis by an oblique plane passing through the promontory of the sacrum behind, and the linea terminalis on each side and in front. These two subdivisions communicate with each other through the superior pelvic aperture (*pelvic inlet*) (fig. 426).

The **greater pelvis**, the expanded portion of the cavity above and in front of the superior pelvic aperture, is bounded on each side by the ilium and posteriorly by the base of the sacrum.

The **lesser pelvis** is that part of the pelvic cavity which lies below and behind the superior pelvic aperture. Its bony walls are more complete than those of the pelvis. It possesses upper and lower apertures and a cavity.

The bony boundaries of the superior pelvic aperture constitute the *brim* of the pelvis (fig. 426). The aperture is somewhat heart-shaped, and encroached upon behind by the forward projection of the promontory of the sacrum. It has three principal diameters: anteroposterior, transverse, and oblique. The *anteroposterior* or *conjugate diameter* extends from the lumbosacral angle to the symphysis pubis; its average measurement is about 110 mm. in the female. The *transverse diameter* extends from the middle of the brim on one side to the same point of the opposite side; its average measurement is about 135 mm. in the female. The *oblique diameter* extends from the iliopectineal eminence to the opposite sacro-iliac joint; its average measurement is about 125 mm. in the female.

FIG. 427.—The diameters of the outlet of the true pelvis (female).



The *cavity* of the lesser pelvis is a short curved canal, considerably deeper behind than in front. It is bounded in front and below by the pubic rami and symphysis; above and behind, by the pelvic surfaces of the sacrum and coccyx; laterally by a smooth, quadrangular area of bone, formed by the pelvic surfaces of the ilium and ischium. It contains, in the recent subject, the sigmoid (pelvic) colon, rectum, urinary bladder, and some of the organs of generation. The rectum is placed at the back of the pelvis, in the curve of the sacrum and coccyx; the urinary bladder is placed anteriorly, behind and above the pubic symphysis. In the female, the uterus and vagina lie between the rectum and the urinary bladder.

The *inferior pelvic aperture (outlet)* is very irregular in shape (fig. 427) and is bounded behind by the apex of the coccyx, and laterally by the ischial tuberosities. These eminences are separated by three notches: one in front—the *pubic arch*—formed by the convergence of the conjoined rami of the ischium and pubis on each side. The other notches one on each side, are formed by the sacrum and coccyx behind, the ischium in front, and the ilium above: they are called the sciatic notches; in the natural state they are converted into foramina by the sacrotuberal and sacrospinal ligaments. When these ligaments have been preserved, the outlet of the pelvis is lozenge-shaped, and is bounded, in front, by the inferior pubic ligament and the conjoined rami of the pubis and the ischium; laterally, by the ischial tuberosities; behind, by the sacrotuberal ligaments and the tip of the coccyx.

The *anteroposterior diameter* of the inferior aperture of the pelvis extends from

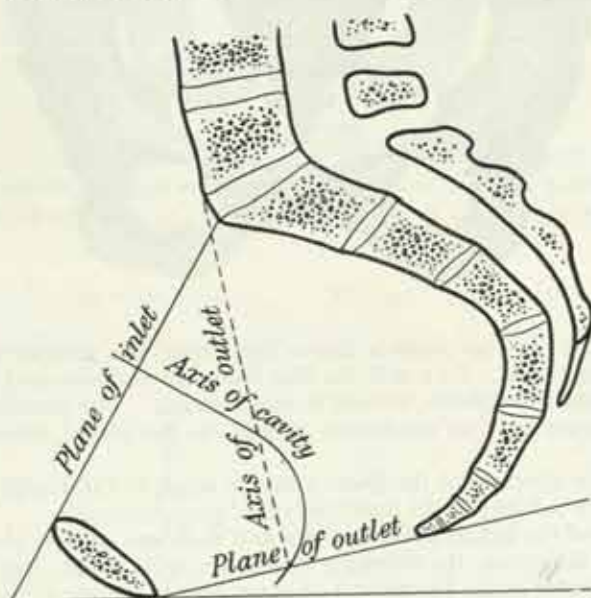
the apex of the coccyx to the lower part of the pubic symphysis; its measurement is from 90 to 115 mm. in the female. It varies with the length of the coccyx, and is capable of increase or diminution, on account of the mobility of that bone. The *transverse diameter*, measured across the widest part of the inferior aperture is about 115 mm. in the female.*

Axes (fig. 428).—The axis of the superior aperture, i.e. a line at right angles to the plane of the superior aperture through its centre, is directed downwards and backwards, and if the line is prolonged it passes through the umbilicus above and the middle of the coccyx below. The axis of the inferior aperture is directed downwards and slightly backwards; if prolonged upwards it touches the base of the sacrum. The axis of the cavity—i.e. an axis at right angles to a series of planes between and including those of the superior and inferior apertures—is curved like the cavity itself: this curve is parallel with that of the sacrum and coccyx.

Inclination of the pelvis (fig. 428).—In the erect posture, the pelvis is placed obliquely with regard to the trunk: the plane of the superior aperture forms with the horizontal plane an angle of from 50° to 60° , and that of the inferior aperture one of about 15° .

The pelvic surface of the pubic symphysis faces upwards and backwards, the concavity of the sacrum and coccyx downwards and forwards. The position of the pelvis in the erect posture may be demonstrated by holding it so that the anterior

FIG. 428.—A median sagittal section through a female pelvis.



Note.—It should be observed that, as depicted in this section, the curve of the sacrum affects the lower part of the third and the upper part of the fourth sacral vertebra. In many cases the curve is restricted to the fourth vertebra only.

In this instance the axis of the outlet, when produced upwards, touched the upper part of the disc of the lumbosacral joint.

superior iliac spines and the top of the pubic symphysis are in the same vertical plane.

In the sitting posture the body rests on the medial and lower parts of the ischial tuberosities (p. 401), and a coronal plane drawn through the anterior superior iliac spines passes through the acetabula. The lumbosacral angle is considerably reduced and the projection of the sacral promontory is correspondingly diminished.

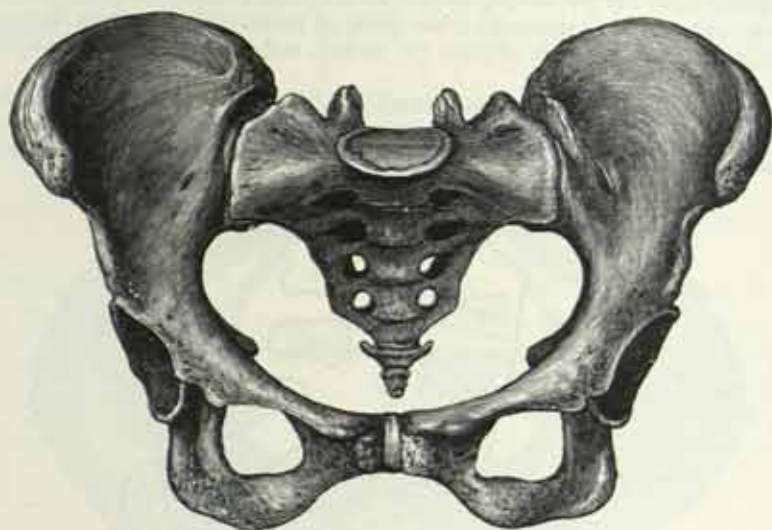
Differences between the male and female pelves (figs. 429-432).—Sexual

* The measurements of the pelvis given above are fairly representative, but different figures are given by different authors, no doubt mainly due to difference in the physique and stature of the population from whom the measurements have been taken.

characters are more pronounced in the bones of the pelvis than in any other bones in the body. The female pelvis is specially adapted to facilitate the passage of the foetal head during parturition and it must therefore provide more accommodation than is necessary in the male pelvis, while its depth must be diminished. The essential differences were well summed up by Arthur Thomson, who described the male pelvis as a long section of a short cone and the female pelvis as a short section of a long cone. There are, however, very many differences in detail, most of which can be referred to these fundamental distinctions.

As a whole, the bones of the female pelvis are more delicate and their muscular impressions are not so well marked. The ilia are more vertical and, although the

FIG. 429.—The female pelvis. Anterior aspect.
From a specimen in the museum of the Royal College of Surgeons of England.



distance between the iliac crests is less in the female, the anterior superior iliac spines are farther apart. As a rule, the iliac fossæ are shallower and the curves of the crest, as seen from above, are not so pronounced. The prominence of the hips in the female may be attributed, in part, to the sexual characters of the ilium.

The superior aperture of the lesser pelvis is larger in the female and is more nearly circular in outline; in the male it is typically heart-shaped.

The cavity of the female pelvis is wider and shallower, and, in the production of this general difference, the following factors are to be noted. (1) The sacrum is shorter and wider in the female and its upper part is straight (p. 247). (2) The depth of the pubic symphysis is less and the distance between the two pubic tubercles is greater in the female. (3) The sciatic notches are wider and shallower, and the spines of the ischia do not project inwards to the same extent as they do in the male.

The inferior aperture is larger in the female, since (1) the pubic arch is wider and more rounded and it will almost always admit a set square: whereas in the male it is more pointed and usually less than a right angle; (2) the ischial tuberosities are more everted; and (3) the coccyx is more movable.

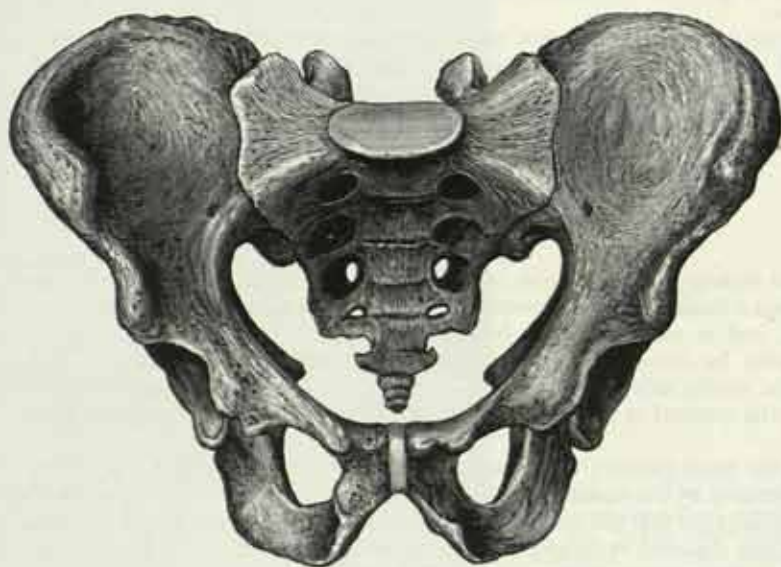
The male pelvis possesses one positive sexual character: the margins of the pubic arch are more everted, owing to the larger size of the crura of the penis.

The following additional differences should also be mentioned. (1) The acetabula are smaller in the female: they are wider apart and face more definitely forwards.* As a result the transverse diameter of the acetabulum is distinctly less

* D. E. Derry, *J. Anat. and Physiol.*, 43, 1919.

than the distance from its anterior margin to the pubic symphysis. In the male, on the other hand, the two measurements are practically equal. (2) The obturator foramen is smaller in the female and tends to be triangular in shape. In the male it is more nearly oval in outline, but this difference is not of great value as a sexual

FIG. 430.—The male pelvis. Anterior aspect.

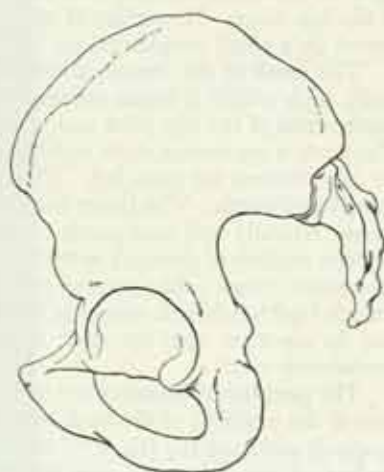


character. (3) The pre-auricular sulcus (p. 398) is more constantly present in the female ilium, and its presence is presumably associated with the existence of a more movable sacro-iliac joint. (4) The auricular surface of the sacrum is limited to the

FIG. 431.—Profile view of male pelvis.



FIG. 432.—Profile view of female pelvis.



first and second sacral vertebræ in the female, but in the male it usually extends to the middle of the third vertebra.

The size of the pelvis varies not only in the two sexes, but also in different members of the same sex, and does not appear to be greatly influenced by the height of the individual. Women of short stature, as a rule, have broad pelvises. Occasionally

the pelvis is contracted in all its dimensions, and its diameters may be as much as 12.5 mm. less than the average, and this even in well-formed women of average height. The principal divergences, however, are found at the superior aperture, and affect the relation of the anteroposterior to the transverse diameter. Thus the superior aperture may be elliptical either in a transverse or an anteroposterior direction, the transverse diameter in the former, and the anteroposterior in the latter, greatly exceeding the other diameters; in some instances it is almost circular.

In the *fœtus*, and for several years after birth, the pelvis is small in proportion to that of the adult, and the projection of the lumbosacral angle less marked. The characteristic differences between the male and female pelves are distinctly indicated as early as the fourth month of intrauterine life.

THE FEMUR (figs. 435-438)

The **femur**, or thigh-bone, is the longest and strongest bone in the body. It possesses a shaft and two extremities. The shaft is almost cylindrical in most of its length, and is curved with a *forward convexity*. The head, which is rounded, can easily be distinguished from the widely expanded lower end: it projects from the *medial* side of the *upper* end of the shaft. This information is sufficient to enable the student to assign a given femur correctly to its appropriate side of the body.

In the erect posture the femora are placed obliquely (fig. 247). Their heads are separated by the breadth of the lesser pelvis and their shafts incline downwards and medially, so that the medial sides of the two knees almost touch. As the bones of the legs descend vertically from the knees, the obliquity of the femoral shafts results in the approximation of the feet in the erect attitude and the provision of a narrow base for the support of the weight of the body. The narrowness of the base detracts from the stability of the body but greatly facilitates movements and increases the speed with which they can be executed. The degree of obliquity of the shafts varies in different individuals, but is usually greater in women on account of the greater breadth of the pelvis.

The **upper end** of the femur (fig. 433) comprises a head, a neck, a greater and a lesser trochanter.

General features.—The **head** forms rather more than half a sphere; it is directed upwards, medially and slightly forwards, to articulate with the acetabulum of the hip-bone. Its surface is smooth, and is marked a little below and behind its centre by a small roughened pit or *fovea*.

The **neck** of the femur, which is about 5 cm. long, connects the head and the shaft, with which it forms an angle of about 125° . This angulation facilitates the movements of the hip-joint and enables the lower limb to swing clear of the pelvis. The neck is narrowest at its middle and is wider at its lateral than at its medial end. Its two borders are rounded. The upper border is nearly horizontal and is gently concave upwards. The lower border is straight but oblique, and is directed downwards, laterally and backwards to meet the shaft near the lesser trochanter. The anterior surface of the neck is flattened and its junction with the shaft is marked by a prominent rough ridge, termed the *intertrochanteric line*. The posterior surface is convex backwards and upwards in its transverse axis, and concave in its long axis, and its junction with the shaft is marked by a rounded ridge, termed the *intertrochanteric crest*.

The **greater trochanter** is a large, quadrangular eminence, situated at the upper part of the junction of the neck with the shaft. Its posterosuperior portion projects upwards and medially (fig. 437) so as to overhang the adjoining part of the posterior surface of the neck; in this situation its medial surface presents a roughened, depressed area, termed the *trochanteric fossa*. The upper border of the trochanter lies one hand's-breadth below the tubercle on the iliac crest, and is on a level with the centre of the head of the femur. The anterior surface of the trochanter presents a roughened impression; its lateral surface is divided into two areas by an oblique, flattened strip, wider above than below, which runs downwards and forwards across it. The lateral surface of the trochanter can be palpated in the living subject (fig.



FIG. 1.—Radiograph of an adult knee. The gap visible between the lateral condyles of the femur and tibia is occupied by the articular cartilage of the two bones and the lateral meniscus.



FIG. 2.—Radiograph of the knee of a child aged 7½ years. Note that the styloid process of the head of the fibula and the tubercles of the intercondylar eminence of the tibia are still cartilaginous and therefore cannot be recognised.

PLATE XVI



FIG. 1.—Radiograph of the knee of a boy aged 16 years. Lateral view. Note that the upper epiphysis of the tibia includes the tibial tuberosity, which is indicated by the arrow.



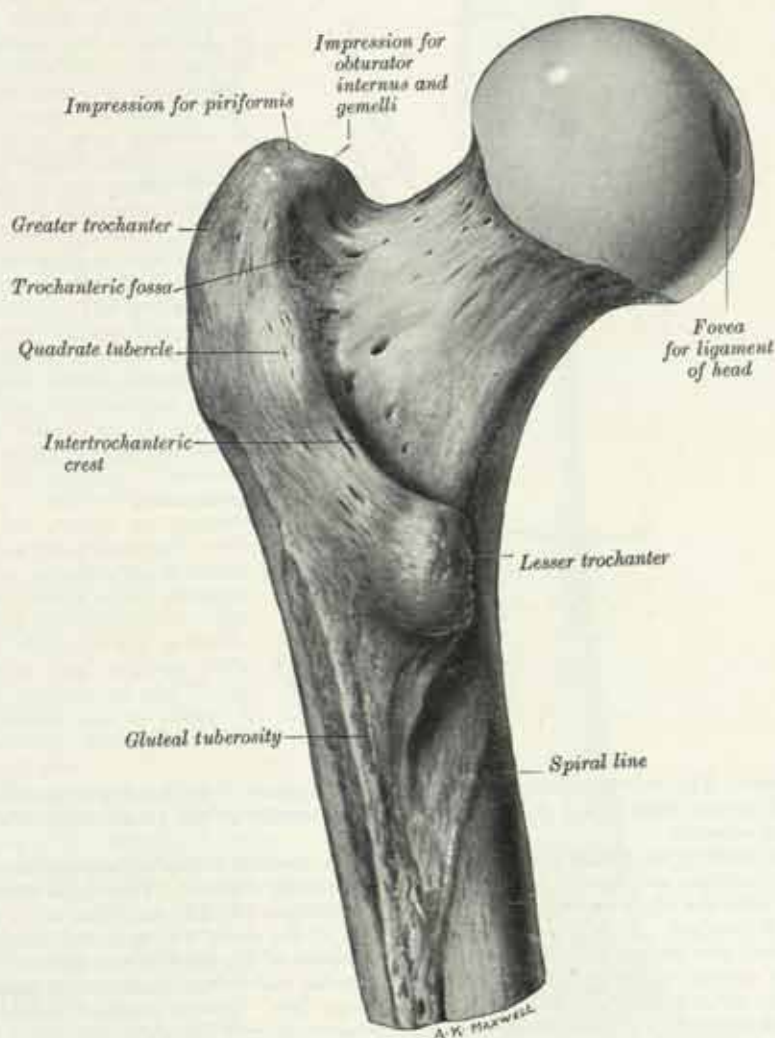
FIG. 2.—Radiograph taken after injection of air into the knee-joint, showing the shadow thrown by a normal medial meniscus. The upper arrow points to the medial ligament and the lower to the medial meniscus. Aerogram lent by Wing-Commander A. A. Butler, R.A.F.

434), and, when the adjoining muscles are relaxed, the trochanter can be gripped between the thumb and fingers.

The **lesser trochanter** (fig. 433) is a conical eminence, which projects medially and backwards from the shaft at its junction with the lower and posterior part of the neck. Its summit and anterior surface bear a roughened impression, but its posterior surface, which lies at the lower end of the intertrochanteric crest, is smooth and even. It is placed too deeply to be felt in the living subject.

The *intertrochanteric line* marks the junction of the anterior surface of the neck with the shaft of the femur (fig. 435). It is a prominent roughened ridge, which commences in a tubercle at the upper and medial part of the anterior surface of the greater trochanter and runs downwards and medially. It reaches the lower border of

FIG. 433.—The upper part of the left femur. Viewed from behind.



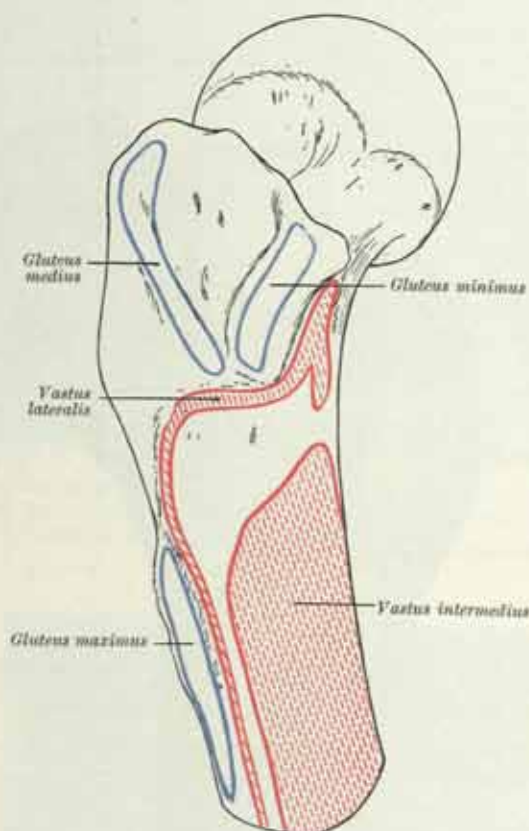
the neck on a level with the lesser trochanter, but in front of it. Below, it is continuous with the *spiral line* (p. 412).

The *intertrochanteric crest* (fig. 437) marks the junction of the posterior surface of the neck with the shaft of the femur. It is a smooth rounded ridge, which commences at the posterosuperior angle of the greater trochanter and runs downwards and medially to terminate at the lesser trochanter. A little above

its middle it presents a low rounded elevation, sometimes termed the *quadrate tubercle*.

Particular features.—The **head** of the femur is entirely intracapsular and is encircled immediately lateral to its greatest diameter by the acetabular labrum. Its circumference is sharply defined, except on the anterior surface, where the cartilage covered surface extends on to the front of the neck. The fovea which marks the head below and behind its centre (fig. 433) gives attachment to the ligament of the head of

FIG. 434.—The upper part of the right femur. Lateral aspect.



the femur. The inferomedial part of the anterior surface of the head is related to the femoral artery, from which it is separated by the tendon of the *psoas major* and the articular capsule.

The **neck** of the femur is marked by numerous vascular foramina, especially on its anterior surface and on the upper part of its posterior surface. The angle which it makes with the shaft is widest at birth and diminishes steadily until the adult condition is reached. It is less in the female than in the male, owing to the increased breadth of the lesser pelvis and the greater obliquity of the shaft of the femur. The **anterior surface** of the neck is entirely intracapsular and on this surface the capsular ligament extends laterally to the intertrochanteric line. On the **posterior surface** the capsular ligament does not reach the intertrochanteric crest (fig. 433), and only a little more than the medial half of the neck lies within the capsule. The part of the anterior surface adjoining the head is covered with cartilage and is related to the iliofemoral ligament in the erect posture. A faint groove crosses the posterior surface in an upward and lateral direction; it is produced by the obturator externus tendon as it passes to the trochanteric fossa. The neck of the femur does not lie in the same plane as the shaft, but is carried forwards as it passes upwards and medially. On this transverse axis of the lower end of the bone, and this angle is known as the angle of *femoral torsion*.

The **greater trochanter** (fig. 434) provides insertion for most of the muscles of the gluteal region. The *gluteus minimus* is inserted into the rough impression on its anterior surface. The *gluteus medius* is inserted into the oblique, flattened strip, which runs downwards and forwards across its lateral surface. The area in front of this insertion is separated from the tendon by the trochanteric bursa of the *gluteus medius*; the area behind the insertion is covered by the deep fibres of the *gluteus maximus*, and a portion of the trochanteric bursa of that muscle may be interposed. The upper border of the trochanter gives insertion to the *piriformis*, and its medial surface to the common tendon of the *obturator internus* and the two *gemelli*. At their insertions these two tendons are frequently blended with each other. The trochanteric fossa receives the insertion of the *obturator externus*.

The **lesser trochanter** receives the insertion of the *psoas major* on its summit and on the medial part of its anterior surface. The base of the trochanter is expanded and its medial or anterior surface gives insertion to the *iliacus*, which extends downwards for a short distance behind the spiral line. The upper fibres of the *adductor magnus* play over the posterior surface of the lesser trochanter and a bursa is sometimes interposed between them.

The **intertrochanteric line** marks the lateral limit of the capsular ligament of the hip-joint. Its upper part, including the tubercle already noticed, receives the attachment of the upper band of the *iliofemoral* ligament; its lower part receives the lower band of the same ligament. The highest fibres of the *vastus lateralis* arise from the upper end of the line, and the highest fibres of the *vastus medialis* from its lower end.

The **intertrochanteric crest**, above the *quadrate tubercle*, is covered by the *gluteus maximus* muscle; below the

FIG. 435.—The right femur. Anterior aspect.

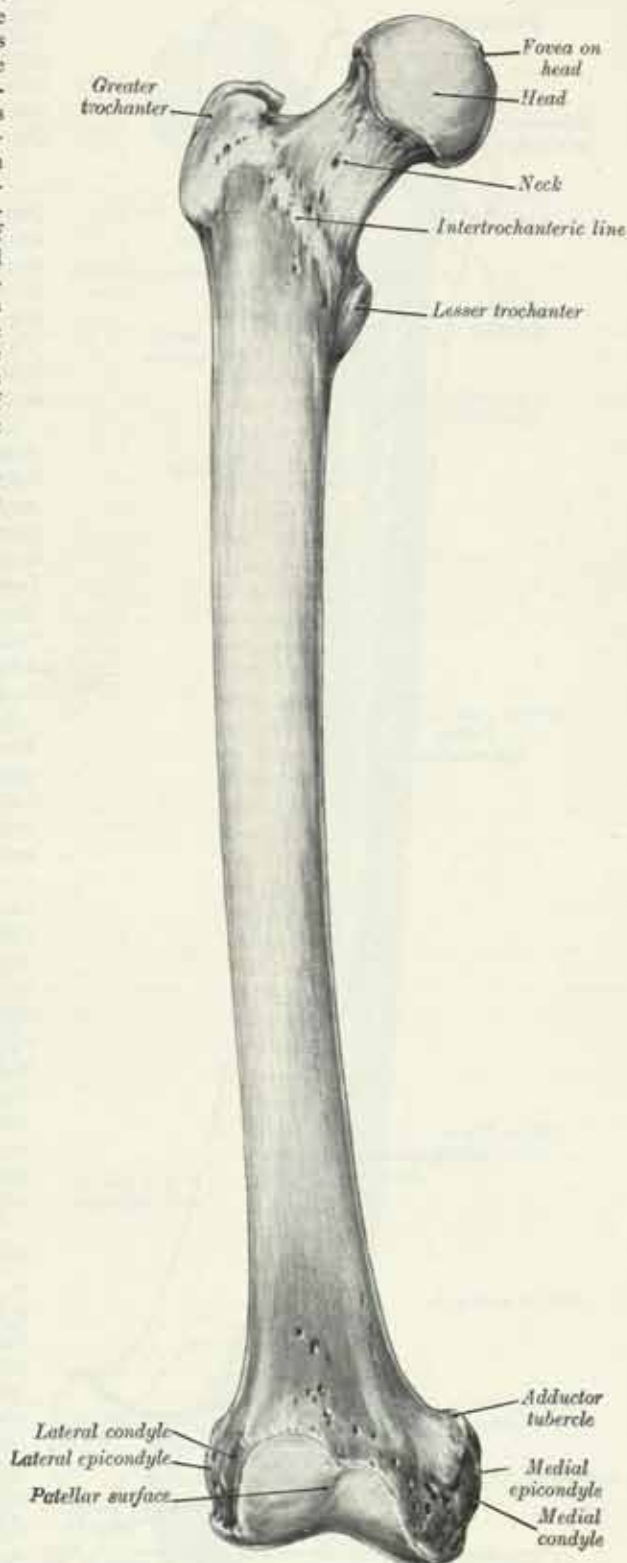
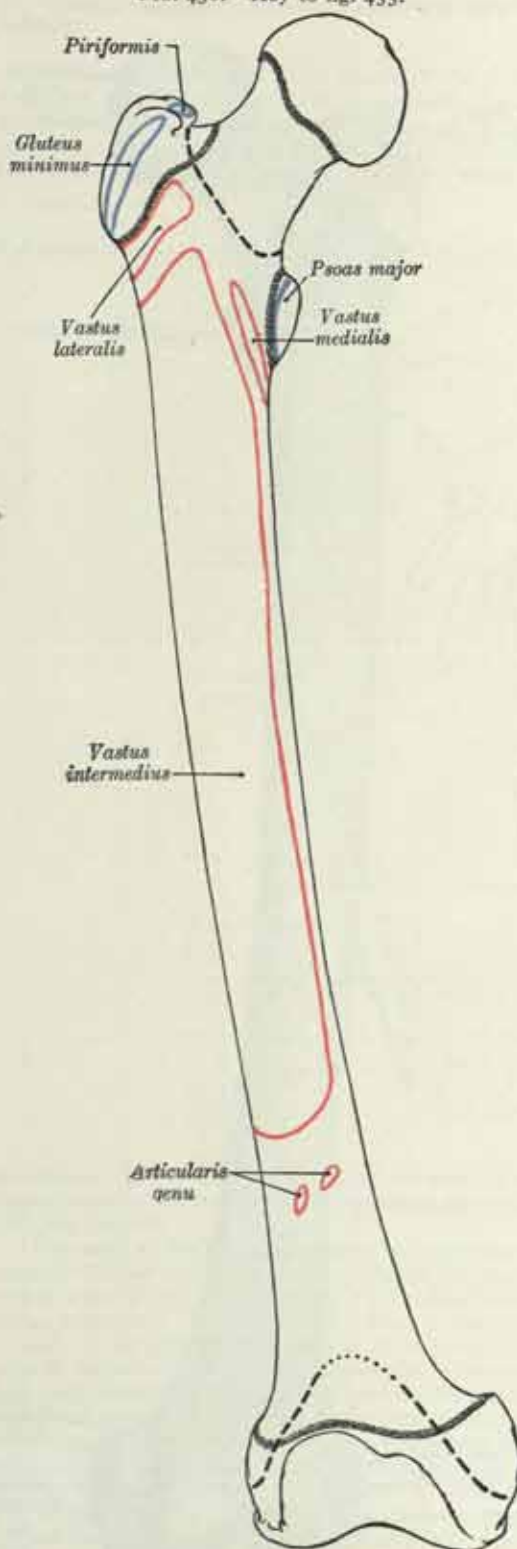


FIG. 436.—Key to fig. 435.



The stippled lines mark the position of the epiphyseal lines. The interrupted lines correspond to the attachments of the capsular ligaments. The dotted part of the lower line indicates the site of communication between the cavity of the knee-joint and the suprapatellar synovial bursa.

tubercle it is separated from that muscle by the quadratus femoris and the upper border of the adductor magnus. The tubercle itself, and a portion of the bone below, receive the insertion of the quadratus femoris muscle (fig. 438).

The **shaft** of the femur (figs. 435 and 437) is thinnest at its middle: it expands a little as it is traced upwards, but it widens appreciably near the lower end of the bone. Throughout its whole extent it is covered with muscles and is difficult to palpate.

In its *middle third* the shaft possesses three surfaces and three borders. The *anterior surface*, which is smooth and gently convex in all directions, is easy to identify. It is placed between the lateral and the medial borders, which are both rounded and ill-defined. The *lateral surface* is directed more backwards than laterally, and is bounded in front by the lateral border and behind by the posterior border. The posterior border is formed by a broad, rough ridge, termed the **linea aspera**, which usually forms a crestlike projection, with distinct lateral and medial lips. In this situation the compact substance is increased in amount in order to compensate for the weakness caused by the curve of the bone. The *medial surface* is directed medially and slightly backwards; smooth, like the two other surfaces, it is bounded in front by the medial border and behind by the linea aspera.

In its *upper third* the shaft presents a fourth surface, which is directed backwards. This *posterior surface* is bounded on the medial side by a narrow, roughened line, often termed the *spiral line*, which is continuous above with the lower end of the intertrochanteric line, and below with the medial lip of the linea aspera. On the lateral side the surface is bounded by a broad, roughened ridge termed the *gluteal tuberosity*, which extends upwards and

laterally to the root of the greater trochanter and is continuous below with the lateral lip of the linea aspera. The posterior surface in this part of the bone is therefore V-shaped.

In its lower third also the shaft possesses a fourth, or *posterior surface*. This posterior surface is placed between the *medial* and *lateral supracondylar lines*, which are continuous above with the corresponding lips of the linea aspera. These two lines form definite but not conspicuous ridges, and of the two the lateral is the more distinct. Near its upper end the medial supracondylar line is in part obliterated; it is in this situation that the principal artery of the limb lies in close relation with the bone as it passes from the thigh to the popliteal fossa. The posterior surface of the lower third forms a flattened, triangular area, which is termed the *popliteal surface* of the femur (fig. 437); in its lower and medial part it presents a rough and slightly elevated area.

Particular features.—The **shaft** (figs. 436 and 438) is thickly covered with muscles and cannot be felt satisfactorily through the skin. Its *anterior* and *lateral surfaces* give origin in their upper three-fourths to the vastus intermedius; below that muscle the articularis genu arises by several small slips from the front of the bone. The lower portion of the anterior surface for 5 or 6 cm. above the patellar articular surface is covered by the suprapatellar bursa, which intervenes between the bone and the muscles mentioned. The lower portion of the lateral surface is covered by the vastus intermedius. The *medial surface* is devoid of muscular attachments and is covered by the vastus medialis.

The vastus lateralis has a linear origin which commences in front at the root of the greater trochanter and follows it to the upper end of the gluteal tuberosity. It then

FIG. 437.—The right femur. Posterior aspect.

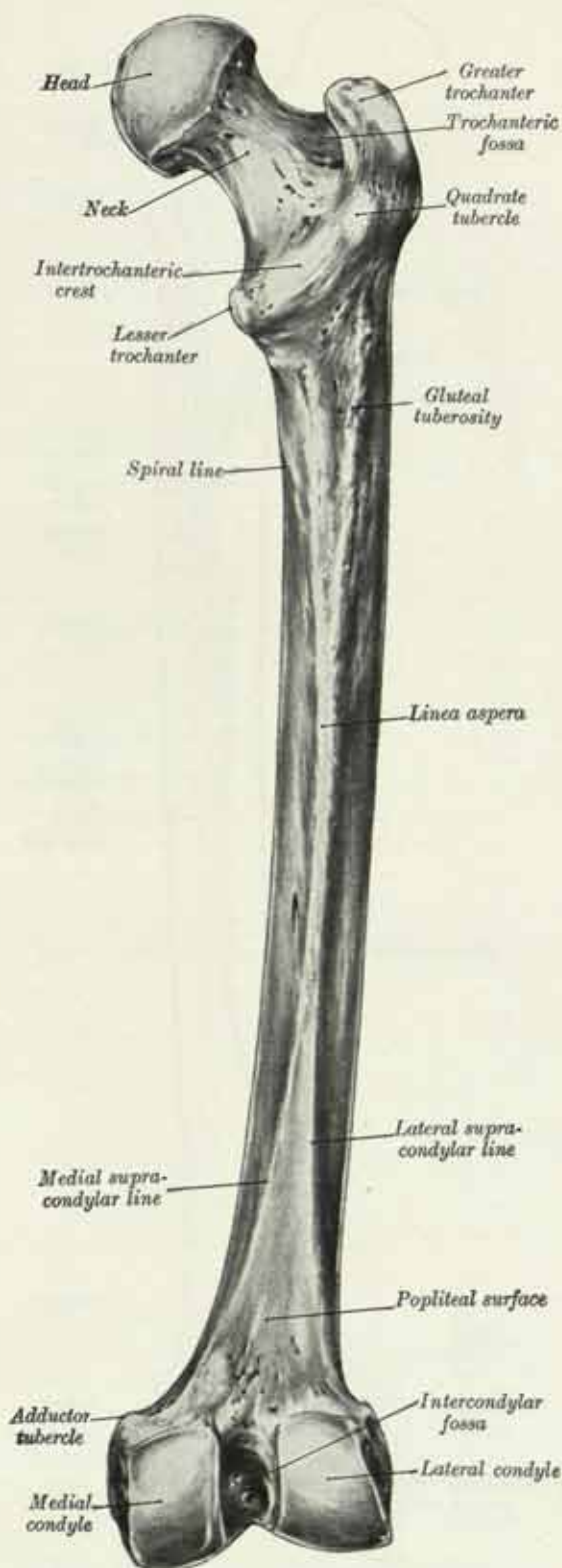
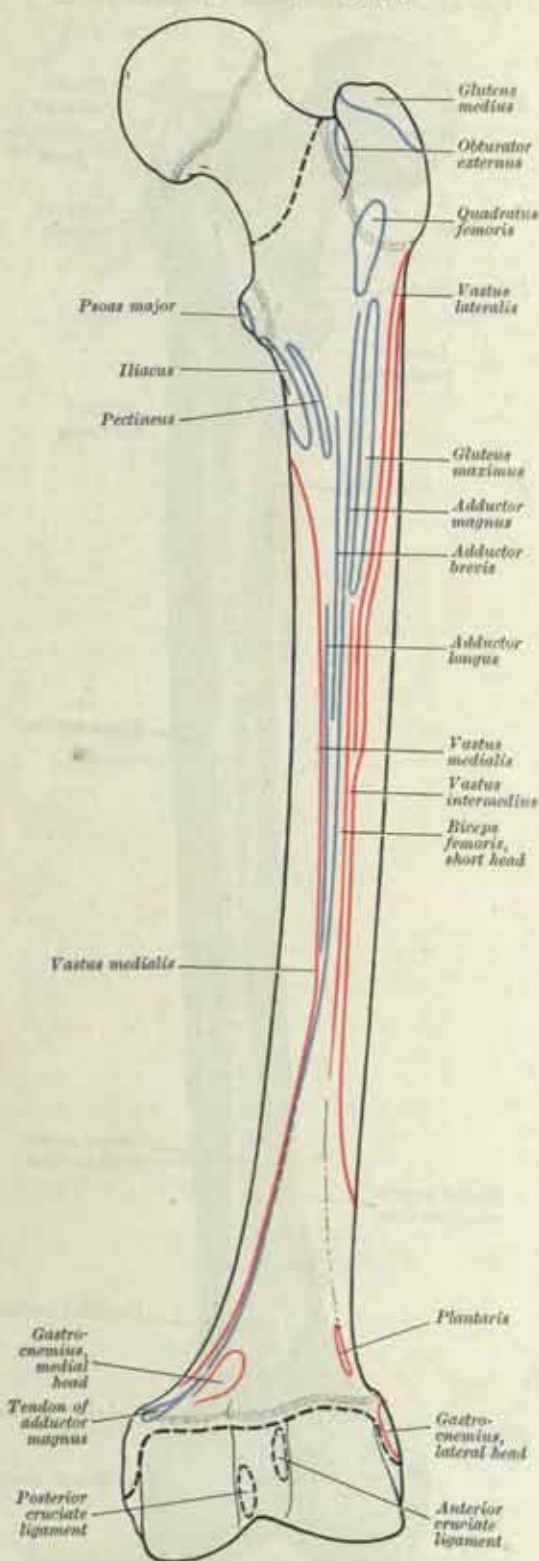


FIG. 438.—Key to fig. 437.



The stippled lines mark the positions of the epiphyseal lines; the interrupted lines indicate the attachments of the capsular ligaments.

descends along the lateral margin of the tuberosity to the lateral lip of the linea aspera, from the upper half of which it takes origin. The vastus medialis also has a linear origin. It commences at the lower end of the intertrochanteric line and follows the spiral line to the medial lip of the linea aspera. At the lower end of the linea aspera it follows the medial supracondylar line in its upper half.

The *gluteal tuberosity* may take the form of an elongated, roughened depression or it may project as a salient ridge. Occasionally a part of it is sufficiently prominent to merit the name of a *third trochanter*. It receives the insertion of the deeper fibres of the lower half of the *gluteus maximus* muscle. The medial edge of the tuberosity provides insertion for the pubic fibres of the *adductor magnus*; the succeeding fibres of that muscle are inserted into the linea aspera and the upper part of the medial supracondylar line; the remaining fibres form a stout tendon which is inserted into the *adductor tubercle* (*vide infra*) and sends a membranous expansion to the lower part of the medial supracondylar line.

Between the gluteal tuberosity and the spiral line the posterior surface receives the insertions of the *pectineus* and the *adductor brevis* muscles. The *pectineus* is inserted into a line, sometimes slightly roughened, which descends from the root of the lesser trochanter to the upper end of the linea aspera. The *adductor brevis* is inserted lateral to the *pectineus* and extends downwards to the upper part of the linea aspera, where it is attached medial to the *adductor magnus*.

In addition to the attachments already described, the **linea aspera** receives the insertion of the *adductor longus* and the attachments of the intermuscular septa, and gives origin to the short head of *biceps femoris*. The structures attached to the linea aspera are inseparably blended at their bony attachments. The perforating arteries cross the linea aspera from the medial to the lateral side,

under cover of tendinous arches in the adductor magnus and the short head of the biceps femoris. The foramina for the nutrient arteries are situated close to the linea aspera. They vary in number and position. One is usually placed near the upper end of the linea aspera, and a second, which is not always present, near its lower end. The foramina are directed upwards through the compact substance.

The **popliteal surface** of the femur forms the floor of the upper part of the popliteal fossa. It is covered by a variable amount of fat, which separates the popliteal artery from the bone. The superior medial genicular artery arises from the popliteal artery as it lies in the intercondylar notch. It arches medially above the medial condyle, but is separated from the bone by the medial head of the gastrocnemius, which takes origin from the rough elevation placed a little above the medial condyle. The superior lateral genicular artery arches upwards and laterally above the lateral condyle, but is separated from the bone by the plantaris muscle, which arises from a small roughened area on the lower part of the lateral supracondylar line.

The **lateral supracondylar line** is most distinct in its upper two-thirds, to which the short head of the biceps femoris and the lateral intermuscular septum are attached. Its lower part is marked by a small roughened area which gives origin to the plantaris and often encroaches on to the popliteal surface. The **medial supracondylar line** is feebly marked in its upper two-thirds, where it gives origin to the vastus medialis. Near its upper end it is crossed by the femoral vessels as they enter the fossa from the adductor canal. It is often sharp and prominent for 3 or 4 cm. above the adductor tubercle and in this situation it gives attachment to a membranous expansion from the tendon of the adductor magnus muscle.

The **lower end** of the femur is widely expanded in order to provide a good bearing surface for the transmission of the weight of the body to the top of the tibia. It consists of two prominent masses of bone, termed the *condyles*, which are partially covered by a large *articular surface*. Anteriorly the two condyles are united and are in line with the front of the shaft; posteriorly they are separated by a deep gap, termed the *intercondylar fossa* (*intercondylar notch*), and they project backwards considerably beyond the plane of the popliteal surface.

The *articular surface* forms a broad A-shaped area for articulation with the patella, or knee-cap, above and the tibia below (fig. 439). The *patellar surface* extends over the anterior surfaces of both condyles, but much the larger part of it is on the lateral condyle. It is concave from side to side, being grooved in its long axis to accommodate the posterior surface of the patella. The *tibial surface* is divided into medial and lateral parts by the intercondylar fossa, but anteriorly each part is directly continuous with the patellar surface. The medial part forms a broad strip which covers the convex inferior and posterior surfaces of the medial condyle, and is gently curved with the convexity of the curve directed medially. The lateral tibial surface covers the same aspects of the lateral condyle but forms a rather broader strip, which passes straight backwards.

The **lateral condyle** (fig. 440) is flattened on its lateral surface and is not so prominent as the medial condyle, but it is stouter and stronger, for it is placed more directly in line with the shaft and probably takes a greater share in the transmission of the weight to the tibia. The most prominent point on its lateral aspect is termed the *lateral epicondyle*, and the whole of this surface can be felt through the skin in the living subject. A short groove, deeper in front than behind, separates the lateral epicondyle from the articular margin below and behind. The medial surface of the condyle forms the lateral wall of the intercondylar fossa.

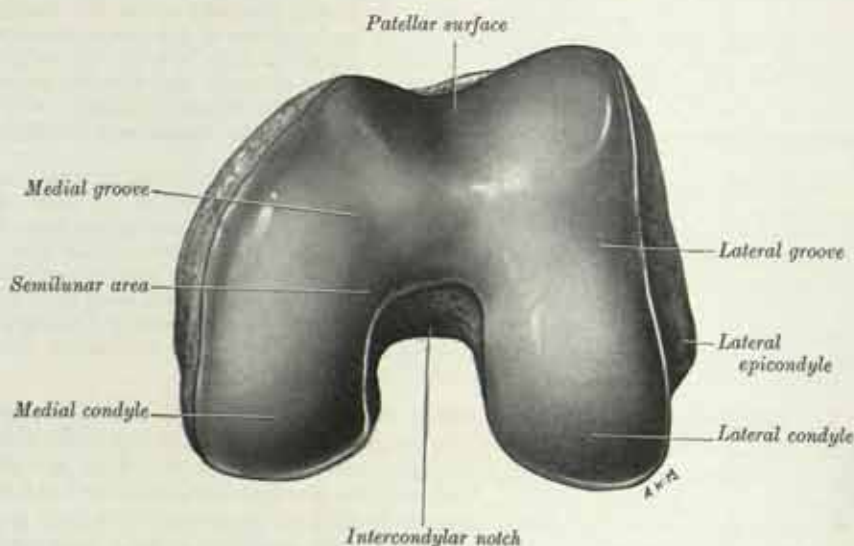
The **medial condyle** possesses a bulging, convex medial aspect, which can be palpated without difficulty. Its uppermost part is marked by a small projection, termed the *adductor tubercle* (fig. 435) because it gives insertion to the tendon of the adductor magnus muscle. The tubercle is an important bony landmark for the surgeon, and can be identified most readily when it is approached from above. The most prominent point on the medial surface of the condyle is below and a little in front of the adductor tubercle and is termed the *medial epicondyle*. The lateral surface of the condyle is roughened and forms the medial wall of the intercondylar fossa.

The **intercondylar fossa** (*intercondylar notch*) separates the two condyles below and behind. In front it is limited by the lower border of the patellar surface, and behind by the *intercondylar line*, which separates it from the popliteal surface.

It lies within the capsular ligament of the knee-joint, but is covered with synovial membrane only over a very limited area.

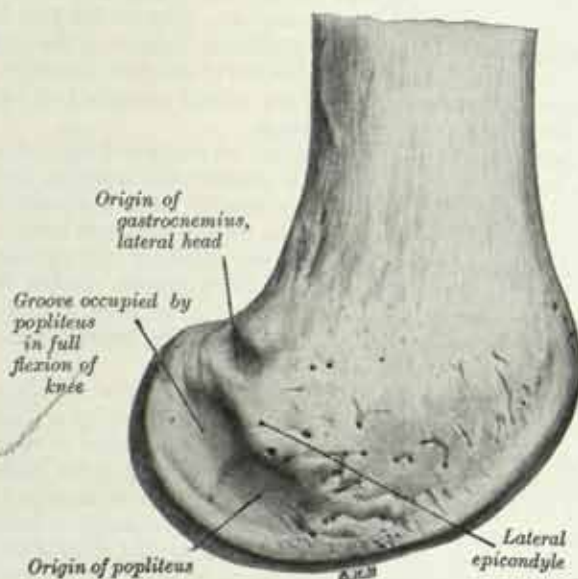
Particular features.—The **patellar surface** extends higher on the lateral than on the medial side; its upper border therefore is oblique and runs downwards and

FIG. 439.—The lower end of the left femur. Inferior aspect.



medially (fig. 435). It is separated from the tibial surfaces by two faint grooves, which cross the condyles obliquely. The lateral groove is the better marked (fig. 439)

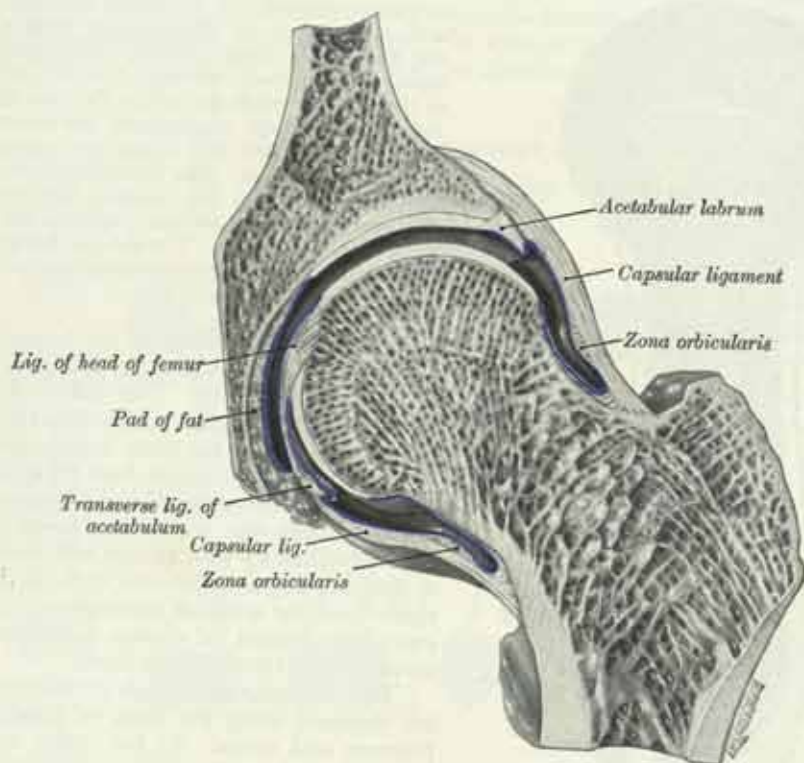
FIG. 440.—The lower end of the right femur. Lateral aspect.



it runs laterally and slightly forwards from the front part of the intercondylar fossa and expands to form a faint triangular depression, which rests on the anterior part of the periphery of the lateral meniscus when the knee-joint is fully extended. The

medial groove is restricted to the medial part of the medial condyle and rests on the anterior edge of the medial meniscus in full extension of the knee. Where this groove ceases the patellar surface is continued backwards on to the lateral part of the medial condyle as a semilunar area adjoining the anterior part of the intercondylar fossa. This area articulates with the medial vertical facet of the patella in forced flexion of the knee-joint; it is not distinctly outlined in most femora. The **tibial surfaces** are convex from side to side and from before backwards. The anteroposterior curvature of the two surfaces is not of the same degree throughout, being much sharper in both

FIG. 441.—A section through the hip-joint.



posteriorly than it is in front. The medial tibial surface is longer than the lateral anteroposteriorly, and shows a slight curve, which is concave to the lateral side, differences which have a bearing on the movements of the knee-joint (p. 528).

In full flexion of the knee-joint the sharply curved posterior parts of the tibial surfaces rest on the tibia and the menisci, while their anterior parts are in contact with the infrapatellar pad of fat. In full extension the anterior parts rest on the tibia, while the posterior parts are in contact with the posterior part of the articular capsule of the knee-joint.

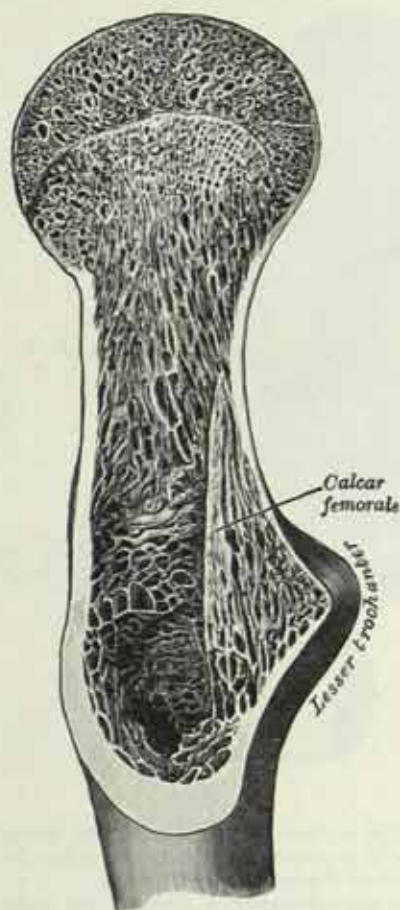
The **medial condyle** projects medially and downwards to such an extent that, despite the obliquity of the shaft, the lower surface of the lower end of the bone is practically horizontal. A curved strip, about 1 cm. wide, adjoining the medial margin of the articular surface, is covered with synovial membrane and lies within the capsule of the knee-joint. The medial epicondyle, which lies above this area, gives attachment to the tibial collateral ligament of the knee joint.

The lateral condyle is less prominent and its lateral surface projects but little beyond the lateral surface of the shaft. The lateral epicondyle gives attachment to the fibular collateral ligament of the knee-joint, and above and behind it the bone bears an impression which gives origin to those fibres of the lateral head of the gastrocnemius that do not arise from the capsular ligament. The deepened, anterior end of the groove which lies between the epicondyle and the articular margin gives origin to the popliteus (fig. 440) muscle; the posterior (or upper) end of the groove lodges the tendon of the muscle only in full flexion of the knee. In extension the tendon passes across the margin of the articular surface below, and sometimes grooves it. Immediately adjoining the articular margin a strip of the lateral condyle, 1 cm.

broad, is intracapsular, and is covered with synovial membrane, with the exception of the depression from which the popliteus arises.

The **intercondylar fossa (intercondylar notch)** separates the projecting portions of the two condyles, and is intracapsular but, to a large extent, extrasynovial. Its lateral wall, formed by the medial surface of the lateral condyle, bears a flattened impression which occupies its upper and posterior part and extends on to the floor of the fossa close to the intercondylar line. This impression gives attachment to the

FIG. 442.—An oblique section through the end of the left femur showing the *calcar femorale*.



upper end of the anterior cruciate ligament. The medial wall of the fossa, formed by the lateral surface of the medial condyle, bears a similar but rather larger impression for the attachment of the upper end of the posterior cruciate ligament; it is placed anteriorly and extends on to the anterior part of the floor of the fossa. These two impressions are relatively smooth, but the rest of the fossa is rough and pitted by vascular foramina, although occasionally the bursal recess between the two ligaments extends upwards to reach it. The *intercondylar line* gives attachment to the capsular ligament and, laterally, to the oblique popliteal ligament of the knee-joint. The anterior border of the fossa receives the upper attachment of the infrapatellar synovial fold (p. 521).

Structure.—The shaft of the femur is a cylinder of compact bone, hollowed by a large medullary cavity. The wall of the cylinder is thick in the middle one-third of the shaft, where the bone is narrowest and the medullary cavity best formed; but above and below this the wall becomes thinner, while the medullary cavity is gradually filled up with spongy substance, so that the upper and lower ends of the shaft—and the articular extremities more especially—consist of spongy substance, invested by a thin compact layer.

The trabeculae in the ends of the femur are disposed along the lines of greatest pressure and stress. In the upper end (figs. 441, 442) the chief lamellae are arranged in the following manner. A series of bony plates at right angles to the articular surface of the head converge to a central dense wedge; this wedge is supported by strong lamellae

which extend to the sides of the neck and are specially marked along its upper and lower borders. Any force therefore applied to the head of the femur is transmitted directly to the central wedge and thence to the junction of the neck with the shaft. This junction is in turn strengthened by a series of dense lamellae which extend from the lesser trochanter to the lateral end of the superior border of the neck; this arrangement will obviously offer considerable resistance to either tensile or shearing force. A smaller bar stretching across the junction of the greater trochanter with the neck and shaft resists the shearing force of the muscles attached to this prominence. These two bars—one at the junction of shaft and neck, the other at the junction of shaft and greater trochanter—form the upper layers of a series of arches which extend across between the sides of the shaft and transmit to it forces applied to the upper end of the bone. A thin vertical plate of bone, named the *calcar femorale* (fig. 442), springs from the compact wall of the shaft in the region of the *linea aspera* and extends into the spongy substance of the neck. Medially, it joins the inner surface of the posterior wall of the neck of the bone; laterally, it continues the plane of the posterior wall of the neck into the greater trochanter, where it shades off into

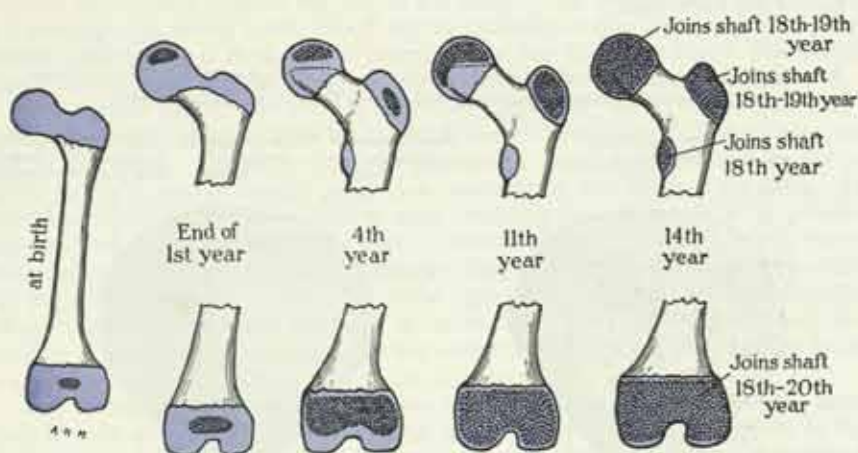
the general spongy substance. It is thus situated in a plane anterior to the trochanteric crest and to the base of the lesser trochanter.

In the lower end, the trabeculae spring on all sides from the inner surface of the cylinder, and descend in a direction perpendicular to the articular surface—the trabeculae above the condyles being the strongest and having a more accurately perpendicular course. In addition to this, there are horizontal planes of spongy substance, which in this situation is divided into a series of cubical compartments.

Ossification (figs. 436, 438, 443).—The femur is ossified from five centres: one each for the shaft, head, greater trochanter, lesser trochanter, and lower end. Except the clavicle, it is the first of the long bones to show traces of ossification. Ossification begins in the middle of the shaft in the seventh week of intrauterine life, and extends upwards and downwards. The secondary centres appear as follows: in the lower end, during the ninth month of intrauterine life (from this centre the

FIG. 443.—Stages in the ossification of the femur.

Note how the neck, which is ossified as an extension from the shaft, invades the cartilaginous head.



condyles and epicondyles are formed); in the head during the first year; in the greater trochanter during the fourth year: and in the lesser trochanter between the twelfth and fourteenth years. The manner in which the epiphysis for the head develops is noteworthy. The ossific centre appears in the upper part of the cartilaginous head and until the age of ten is restricted to that part of the bone, so that the epiphyseal line, as seen in X-ray photographs (Pl. XIII), is horizontal and the lower and medial part of the articular surface is borne on the neck (fig. 443). Thereafter the medial margin of the epiphysis grows over the lower and medial part of the articular surface and covers it completely. As a result, when fully developed, the epiphysis forms a gently hollowed-out cup on the summit of the neck. The epiphyses, derived from the secondary centres, fuse independently with the shaft after puberty; the lesser trochanter joins first, then the greater, then the head, and, lastly, the lower end, which is not united until the twentieth year. It should be noted that the lower epiphyseal plate passes through the adductor tubercle (fig. 436).

Applied Anatomy.—The lower end of the femur is usually the only epiphysis in which ossification has commenced at the time of birth. The presence of this centre of ossification is, therefore, a proof, in a new-born child found dead, that the child was viable, and is always relied upon in medico-legal investigations. The position of the epiphyseal plate should be carefully noted. It is on a level with the adductor tubercle, and the epiphysis does not, therefore, form the whole of the synovial covered portion of the lower end of the bone. It is essential to bear this point in mind when operations are performed on the lower end of the femur, since growth in length of the bone takes place chiefly from the lower epiphyseal cartilage, and any interference with it in a

young child would involve such ultimate shortening of the limb, from want of growth, as to make the limb almost useless.

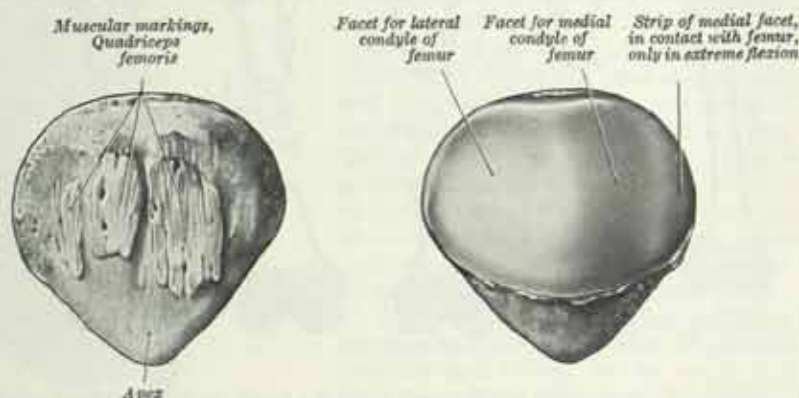
Fractures of the neck of the femur are due to indirect violence and usually occur when the patient trips over some minor obstruction. The trunk continues to move forwards and, overbalancing, falls to the same side, imposing full medial rotation on the thigh and leg.

Below the age of 16 the usual injury suffered from such an accident is a spiral fracture of the shaft of the femur. Between the ages of 16 and 40 the result is usually a 'bucket-handle' tear of the medial meniscus of the knee joint. In older patients, between 40 and 60, the result is a Potts' fracture of the leg, but, in patients over 60, a fracture of the neck of the femur is the common result owing to the senile degenerative changes which have occurred in the bone. Women are more liable to this injury than men, for their bones are more lightly built in the first instance.

THE PATELLA

The **patella** (figs. 444, 445)*—the largest of the sesamoid bones—is situated in front of the knee-joint in the tendon of the quadriceps femoris. It is flattened and triangular, and has an anterior and a posterior surface, three borders, and an apex. In the living subject in the erect attitude, its lower limit lies more than 1 cm. above the line of the knee-joint.

FIGS. 444 and 445.—The left patella. Anterior and posterior aspects. Drawn from a fresh, unmacerated specimen, with the articular cartilage present.



The *anterior surface*, which is readily palpable, is convex, perforated by apertures for the passage of nutrient vessels, and marked by numerous rough, longitudinal striæ. It is separated from the skin by a bursa and is covered, in the recent state, by an expansion from the tendon of the quadriceps femoris; this expansion is continuous below with the superficial fibres of the ligamentum patellæ. The *posterior surface* presents in its upper part a smooth, oval, articular area, divided into two facets by a vertical ridge; the ridge corresponds to the groove on the patellar surface of the femur, and the facets to the medial and lateral parts of the same surface; the *lateral facet* is the broader and deeper. A narrow strip, broader above than below and often inconspicuous in the macerated specimen, is marked off from the medial part of the medial facet. This strip comes into contact with the medial condyle of the femur in extreme flexion of the knee-joint. Below the articular surface the *apex*, which points downwards, is roughened in its lower part for the attachment of the ligamentum patellæ; its upper part is covered by the infrapatellar pad of fat.

The *base* or *superior border* is thick, and sloped from behind, downwards and forwards: it gives attachment, except near its posterior margin, to that portion of the quadriceps femoris which is derived from the rectus femoris and vastus intermedius. The *medial* and *lateral borders* are thinner and they converge below: they

* The results of experimental excision of the patella in dogs were described by Eben J. Carey, Walter Zeit and Bernard F. McGrath, *Amer. J. Anat.* 40, 1928.

give attachment to those portions of the quadriceps femoris which are derived from the vasti medialis et lateralis. Near the junction of the base and lateral border there is a small, shallow, circular depression into which a part of the tendon of the vastus lateralis is inserted.

Structure.—The patella consists of a nearly uniform dense spongy substance, covered by a thin compact lamina. The spaces immediately beneath the anterior surface are arranged parallel with it. In the rest of the bone they radiate from the articular surface towards the other parts of the bone.

Ossification.—The patella is ossified from a single centre, which usually makes its appearance in the second or third year, but may be delayed until the sixth year. Ossification is completed about the age of puberty.

THE TIBIA (figs. 448-451)

General features.—The **tibia** is the medial and much the stronger of the two bones of the leg, and, excepting the femur, is the longest bone of the skeleton. It is prismoid in form, and possesses a shaft and two ends. Its *lower end* is smaller than the *upper end*, and on its *medial side* a stout process, termed the medial malleolus, projects downwards beyond the rest of the bone. The *anterior border* of the shaft is a conspicuous, sharp crest, which curves medially at the lower end towards the medial malleolus; it is the most prominent of the three borders. The student should now be able to refer a given tibia correctly to its appropriate side.

The **upper end** of the tibia is expanded, especially in its transverse axis, to provide a good bearing surface for the body-weight transmitted through the lower end of the femur. It comprises two prominent masses, named the *medial* and *lateral condyles*, and a smaller projection, termed the *tuberosity of the tibia*. The condyles project backwards a little, so as to overhang the upper part of the posterior surface of the shaft, and superiorly each is covered with an articular surface, the two being separated by an irregularly roughened *intercondylar area*. They form visible and palpable landmarks at the sides of the ligamentum patellæ, the lateral condyle being the more prominent of the two. When the knee is flexed passively, the anterior margins of the tibial condyles can be felt readily, and each forms the lower border of a depression at the side of the patellar ligament.

The **medial condyle** is the larger but does not overhang so much as the lateral condyle. Its upper articular surface (fig. 446), oval in outline, is concave in both diameters, and its lateral border projects upwards, deepening the concavity and covering an elevation, termed the *medial intercondylar tubercle*. The posterior surface of the condyle is marked, immediately below the articular margin, by a horizontal, roughened groove. Its medial and anterior surfaces form a rough strip, separated from the medial surface of the shaft by an inconspicuous ridge.

The **lateral condyle** overhangs the shaft, especially at its posterolateral part, which bears on its lower surface a small circular facet for articulation with the upper end of the fibula. The upper surface (fig. 446) is covered with the articular surface for the lateral condyle of the femur. Nearly circular in outline, it is slightly hollowed in its central part, and its medial border extends upwards to cover an elevation, termed the *lateral intercondylar tubercle*. The posterior, lateral and anterior surfaces of the condyle are rough.

The anterior surfaces of the two condyles become continuous in front with a large triangular area, the apex of which is directed downwards and is formed by the tuberosity of the tibia. The lateral edge of this area forms a sharp ridge which separates the lateral condyle from the lateral surface of the shaft.

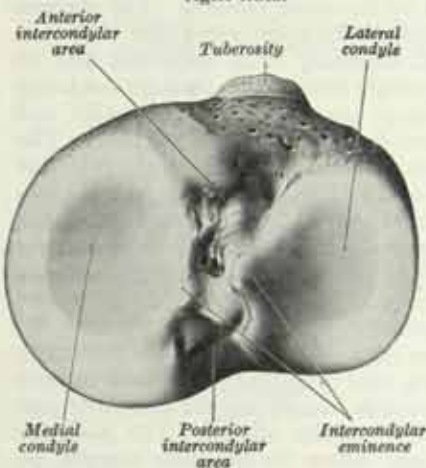
The *intercondylar area* (fig. 446) is a roughened strip on the superior surface, which intervenes between the articular surfaces of the two condyles. It is narrowest at its middle, where it is marked by an elevation termed the *intercondylar eminence*. The lateral and medial parts of the eminence project slightly upwards, and constitute the *lateral* and *medial intercondylar tubercles*. Both behind and in front of the eminence the intercondylar area becomes wider, as the curved margins of the articular surfaces recede from each other.

The **tuberosity of the tibia** is placed at the upper end of the anterior border of

the shaft, and is the truncated apex of the triangular area on the front of the bone where the anterior surfaces of the two condyles become continuous. It forms a low eminence, divided into a lower roughened and an upper smooth portion. The lower part can be felt through the skin, from which it is separated only by a bursa termed the subcutaneous infrapatellar bursa; the upper part gives attachment to the ligamentum patellæ.

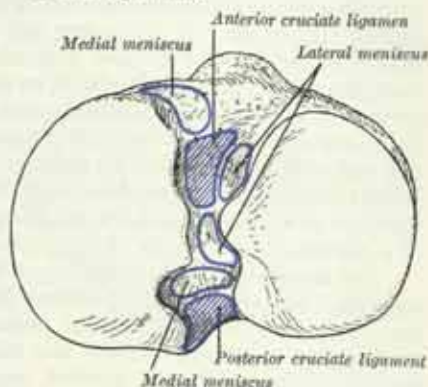
Particular features.—The *articular surface of the medial condyle* is oval in shape, with its long axis anteroposterior and is perceptibly the longer of the two, in conformity with the differences which exist between the tibial surfaces of the two femoral condyles (p. 417). It is related around its anterior, medial and posterior margins to the medial meniscus, and the area of contact is flattened. The imprint of the cartilage, which is widest behind and narrower at the medial side and in front, can often be recognised on the bone. The rest of the surface is concave, and its raised lateral margin covers the medial intercondylar tubercle. The *articular surface of the lateral condyle* is more nearly circular in shape. Like the medial articular surface it is related to the corresponding meniscus, and bears its flattened imprint. Elsewhere the surface is very slightly concave to adapt it to the surface of the corresponding femoral condyle and its raised medial margin is continued on to the lateral aspect of the lateral intercondylar tubercle. The edges of the two articular surfaces are sharp

FIG. 446.—The upper surface of the right tibia.



Note.—The imprints of the menisci were very conspicuous in this specimen.

FIG. 447.—An outline of fig. 446 showing the attachments of the menisci and cruciate ligaments.



except at the posterior part of the lateral surface, where the margin is smooth and rounded; in this situation the tendon of the popliteus is intimately related to the bone.

The *anterior intercondylar area* (fig. 447) is widest anteriorly. In its anteromedial part, just in front of the medial articular surface, it bears a slight depression which gives attachment to the anterior horn of the medial meniscus. Behind that depression a relatively smooth area affords attachment to the lower end of the anterior cruciate ligament. The anterior horn of the lateral meniscus is attached in front of the intercondylar eminence and lies lateral to the anterior cruciate ligament. The *intercondylar eminence* occupies the narrow, middle part of the area, and is surmounted by two tubercles, of which the medial is slightly the more prominent. The posterior slope of the eminence gives attachment to the posterior horn of the lateral meniscus, and behind that the *posterior intercondylar area* inclines downwards and backwards. A depression behind the base of the medial intercondylar tubercle gives attachment to the posterior horn of the medial meniscus. The rest of the area is smooth and affords attachment to the lower end of the posterior cruciate ligament, as far back as the ridge to which the capsular ligament is attached.

The groove on the posterior surface of the *medial condyle* receives the insertion of the semimembranosus muscle; its upper border receives the capsular ligament, and the posterior and shorter fibres of the tibial collateral ligament of the knee-joint. The medial and anterior surfaces of the condyle, which are marked by numerous

vascular foramina, give attachment to the medial patellar retinaculum.

The *fibular facet* on the *lateral condyle* is directed downwards and slightly backwards and laterally. Above and to its medial side the posterior surface of the condyle is grooved by the tendon of the popliteus, but a synovial recess intervenes between the tendon and the bone. The lateral and anterior surfaces of the condyle are separated from the lateral surface of the shaft by a sharp margin which gives attachment to the deep fascia of the leg. An impression on the anterior surface, often well-marked though flattened, affords attachment for the iliotibial tract. Near the fibular facet the uppermost fibres of the extensor digitorum longus and occasionally those of the peroneus longus arise from the lateral surface.

The **tuberosity of the tibia** is subcutaneous in its lower part only, its upper part receives the attachment of the ligamentum patellæ. The two areas are sometimes separated by a rough crest, which receives the superficial fibres of the ligament. Above the tuberosity the bone is related to the deep surface of the ligament, but the deep infrapatellar bursa and some fibro-fatty tissue intervene.

The **shaft** of the tibia (figs. 448, 450) is triangular on section, possessing medial, lateral and posterior surfaces, separated by anterior, interosseous and medial borders. It is thinnest at the junction of its middle and lower thirds, but expands considerably towards its upper and lower ends.

The *anterior border* commences at the tuberosity of the tibia and runs downwards to the medial malleolus. It is subcutaneous throughout its whole length, and, except in its lower fourth, where it is rounded and indistinct, forms a sharp crest, which is familiarly known as the 'shin.' It is not straight, but follows a slightly sinuous course and its lower fourth diverges towards the medial side. The *interosseous border* commences below and a little in front of the fibular facet on the lateral condyle and descends to reach the anterior border of the fibular

FIG. 448.—The bones of the left leg.
Viewed from in front.

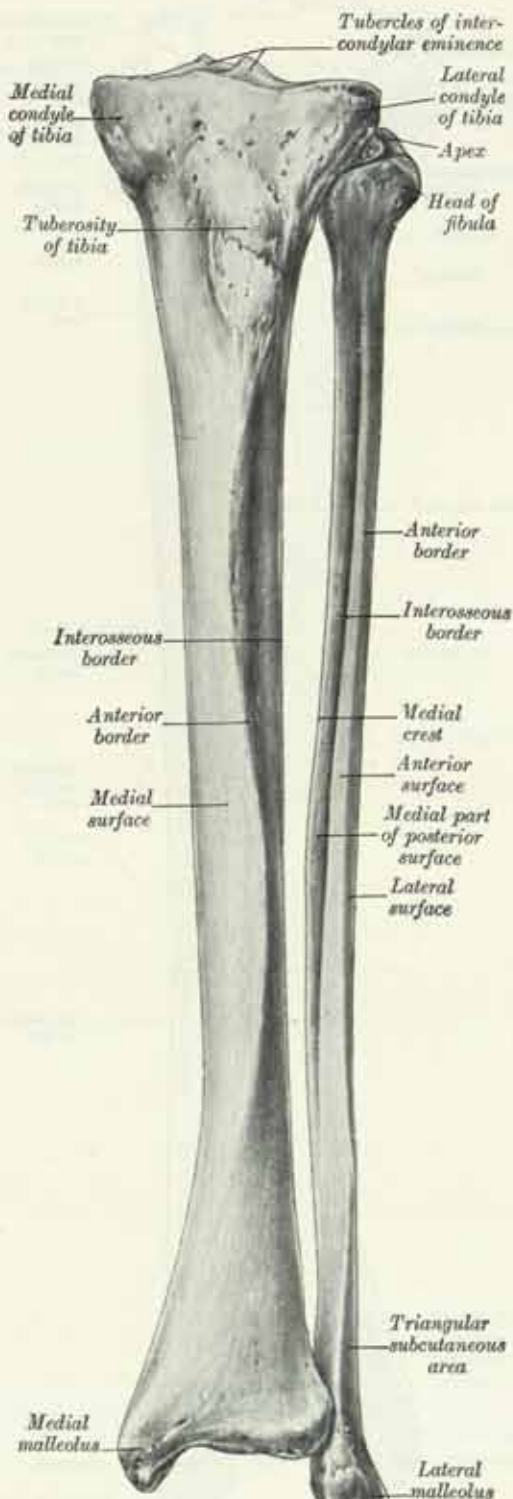
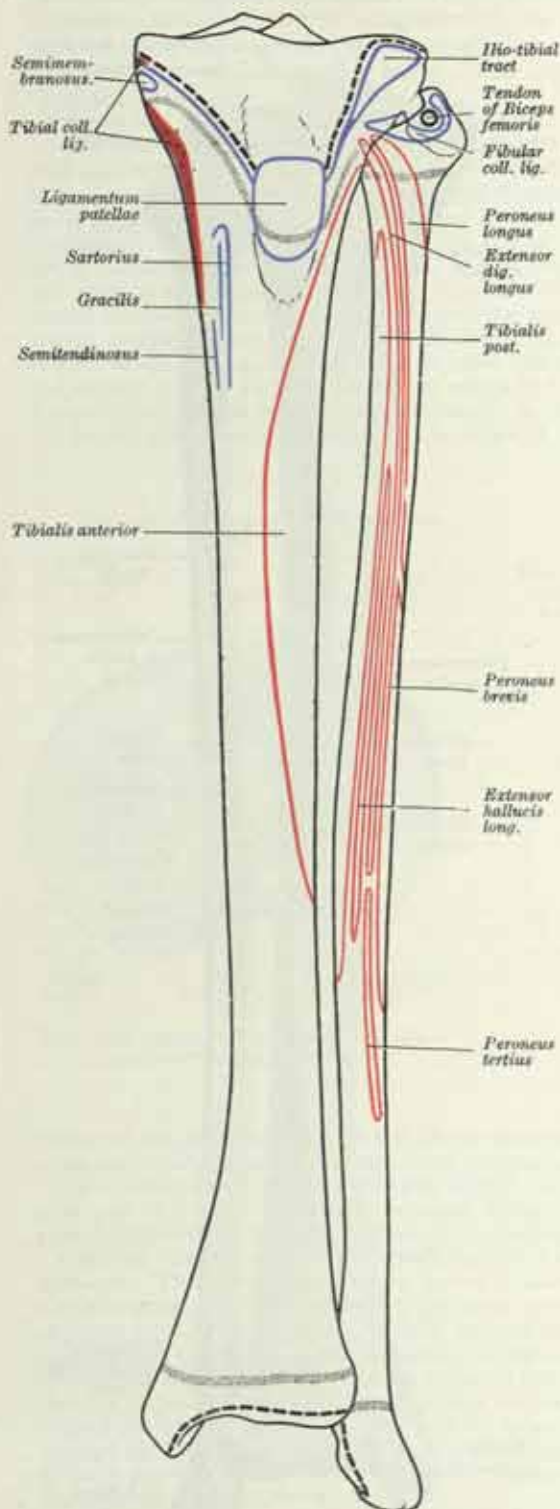


FIG. 449.—Key to fig. 448.



The stippled lines indicate the positions of the epiphyseal lines; the interrupted lines correspond to the attachments of the capsular ligaments.

notch, which marks the lateral aspect of the lower end of the tibia. In nearly the whole of its length it affords attachment to the interosseous membrane which connects the tibia to the fibula. As a rule it is poorly defined at its upper end, but is easily identified in the rest of its extent. The *medial border* commences below the anterior end of the groove on the medial condyle and runs downwards to the posterior margin of the medial malleolus. Its upper and lower fourths are rounded and ill-defined, but its middle third is sharp and distinct.

The *medial surface* is bounded in front by the anterior border, and behind by the medial border. It is broad and smooth, and is subcutaneous throughout practically its whole extent. The *lateral surface*, also broad and smooth, is placed between the anterior and the interosseous borders. In its upper three-fourths it is directed laterally and is slightly concave from before backwards. Its lower fourth is carried round on to the front of the bone, owing to the deviation of the anterior border to the medial side and the forward inclination of the lower part of the interosseous border. This part of the surface is somewhat convex forwards. The *posterior surface* is bounded by the interosseous and the medial borders, and is widest at its upper end, where it is crossed from above downwards and medially by an oblique, roughened ridge, termed the *soleal line*. The area below this line is subdivided by a faint *vertical line*, which begins at or just below the middle of the soleal line and soon fades away. A prominent vascular groove marks the bone near the upper end of the vertical line and descends to enter the large nutrient foramen; it may be situated either on the lateral or on the medial side of the vertical line.

Particular features.—The *anterior border* provides attachment for the deep fascia of the leg. A little above the medial malleolus it receives the medial end of the

superior extensor retinaculum. Above the soleal line the *medial border* gives attachment to the fascia covering the popliteus muscle and to the posterior fibres of the tibial collateral ligament of the knee-joint; below the soleal line it gives origin for a short distance to fibres of the soleus muscle and attachment to the fascia which covers the deep muscles of the leg. At its lower end it becomes continuous with the medial border of the groove which lodges the tendon of the tibialis posterior muscle. The *interosseous border* gives attachment to the interosseous membrane of the leg, except at its upper and lower ends. Its upper end is scarcely recognisable, and in this situation there is a large gap in the interosseous membrane for the passage of the anterior tibial vessels. Its lower end forms the anterior boundary of the fibular notch and gives attachment to the anterior tibiofibular ligament.

The *medial surface* is usually roughened close to the upper part of the medial border over an area nearly 5 cm. long and 1 cm. wide; this area gives attachment to the longer fibres of the tibial collateral ligament of the knee-joint. In front of this roughened area the surface provides insertion for the tendons of the sartorius, gracilis and semitendinosus muscles, which however rarely produce markings on the bone. The gracilis, above, and the semitendinosus muscle, below and behind, are inserted immediately in front of the ligamentous area; the sartorius is inserted into a line which commences above and descends in front of the two other insertions (fig. 449). The rest of surface is covered only by superficial fascia and skin, but its lower part is crossed obliquely by the long saphenous vein, as it ascends from in front of the medial malleolus.

The *lateral surface* gives origin in its upper two-thirds, or less, to the tibialis anterior muscle. Its lower part is devoid of muscular attachments, but is crossed by the tendon of the tibialis anterior

FIG. 450.—The bones of the left leg.
Viewed from behind.

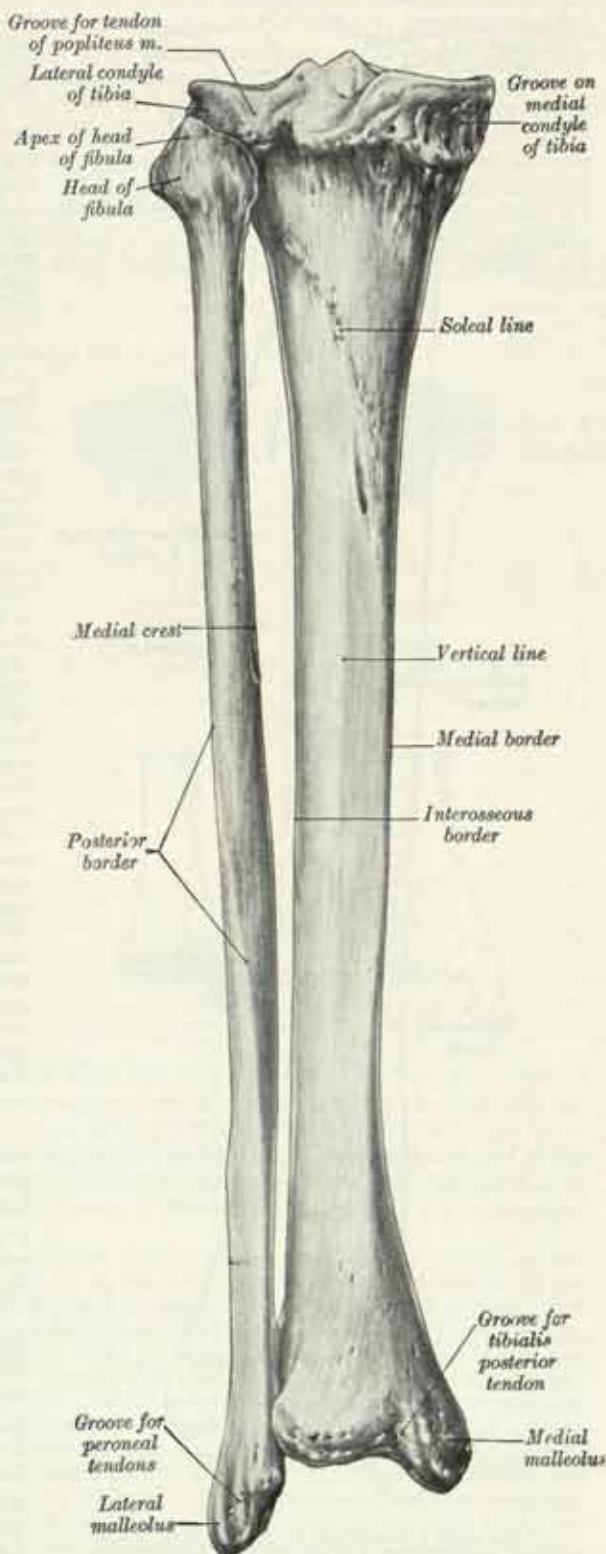
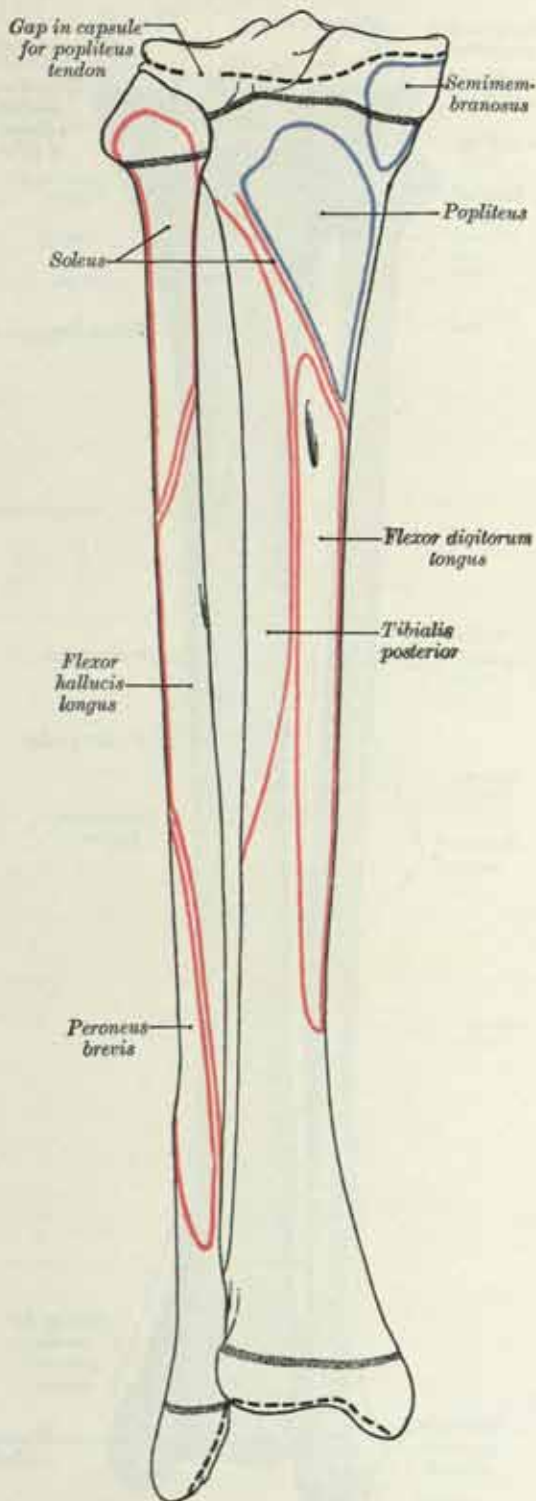


FIG. 451.—Key to fig. 450.



The stippled lines indicate the positions of the epiphysal lines: the interrupted lines correspond to the attachments of the capsular ligaments.

(which lies along the lateral side of the anterior border), the extensor hallucis longus, the anterior tibial vessels and nerve, the extensor digitorum longus and peroneus tertius, in that order from the medial to the lateral side.

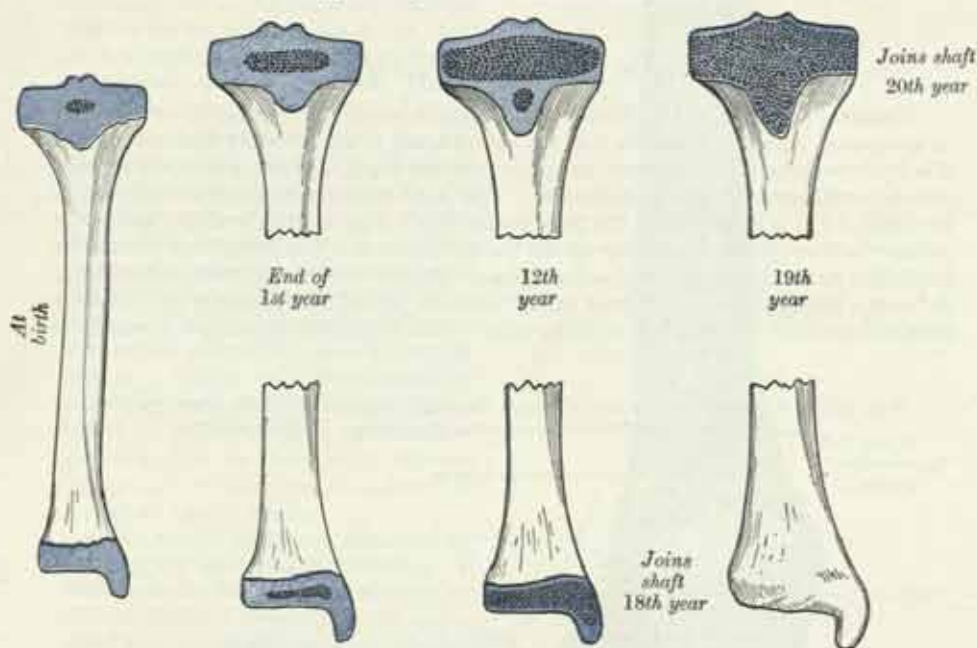
The *posterior surface* gives insertion to the popliteus over the triangular area above the soleal line, with the exception of the area adjoining the fibular facet. The *soleal line* gives attachment to the strong fascia which covers the popliteus muscle, and to the soleus muscle, its covering fascia, and the fascia covering the deep muscles of the leg. The upper end of the line does not reach the interosseous border and is marked by a tubercle, which gives attachment to the medial end of the tendinous arch in the soleus. Lateral to that tubercle the posterior tibial vessels and nerve descend on the surface of the tibialis posterior. Below the soleal line, the *vertical line* separates the origin of the flexor digitorum longus on the medial side from the origin of the tibialis posterior (fig. 451). The lower fourth, or more, of the posterior surface is devoid of muscular attachments, but is intimately related to the tendon of the tibialis posterior as it runs downwards and medially to reach the groove on the back of the medial malleolus. The flexor digitorum longus lies on the posterior surface of the tibialis posterior, crossing it obliquely from the medial to the lateral side, but the posterior tibial vessels and nerve and the flexor hallucis longus come into contact with the lateral part of this surface for a short distance inferiorly.

The *lower end* of the tibia is greatly expanded, and its medial portion projects downwards to form the medial malleolus. It possesses anterior, medial, posterior, lateral and inferior surfaces.

The *anterior surface* is smooth and bulges forwards beyond the inferior surface, from which it is separated by a narrow groove. It is continuous above with the lateral surface of the shaft (p. 424). The *medial surface* also is smooth and is continuous above with the medial surface of the shaft and below with the medial surface of the medial malleolus. It is

subcutaneous and can easily be felt through the skin. The *posterior surface* is crossed at its medial end by a groove which is usually conspicuous and can be traced down on to the posterior surface of the medial malleolus. Elsewhere this surface of the lower end is smooth and is continuous above with the posterior surface of the shaft. The *lateral surface* is formed by a triangular notch, termed the *fibular notch*, which is intimately related to the lower end of the fibula. The anterior and posterior borders of the notch are salient and converge to meet above on the interosseous border of the bone. The floor of the notch is roughened in its upper part for the attachment of the interosseous ligament which binds the lower ends of the two bones securely together. Its lower part is smooth and is sometimes covered with articular cartilage. The *inferior surface* is smooth for articulation with the body of the talus. Wider in front than behind, it is concave from before backwards and slightly convex from side to side. Medially it is continuous with the articular surface of the medial malleolus.

FIG. 452.—Stages in the ossification of the tibia.



The **medial malleolus** is a short but stout process. Its lateral surface is smooth and covered with a comma-shaped articular facet, which articulates with the medial side of the talus. Its anterior surface is rough, and its posterior surface bears the lower end of the groove that marks the posterior surface of the lower end of the bone. The lower border of the malleolus is pointed in front, and behind that, it presents a depression for the attachment of the deltoid ligament of the ankle-joint.

Particular features.—The *anterior surface* of the lower end is related to the tendons, vessels and nerve which lie on the lower part of the lateral surface of the shaft and have already been enumerated (p. 426). The narrow groove adjoining the anterior border of the inferior surface gives attachment to the anterior part of the articular capsule of the ankle-joint. The groove on the *posterior surface* lodges the tendon of the *tibialis posterior*, which at that level usually separates the *flexor digitorum longus* tendon from the bone. More laterally the posterior tibial vessels and nerve and the *flexor hallucis longus* tendon are in contact with this surface. The floor of the *fibular notch*, especially in its rough upper part, gives attachment to the interosseous *tibiofibular* ligament; its lower smooth part may be covered with articular cartilage. The anterior and posterior borders of the notch give attachment respectively to the anterior and posterior *tibiofibular* ligaments. The *medial malleolus* is shorter than the lateral malleolus, which lies on a more posterior plane. Its anterior surface gives attachment to the anterior part of the articular capsule of the ankle-joint. Its

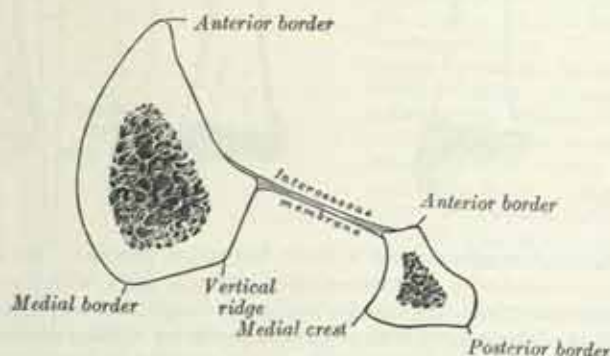
posterior surface is grooved by the tibialis posterior tendon, and the raised, medial margin of the groove gives attachment to the flexor retinaculum. The upper end of the deltoid ligament is attached to the lower border of the malleolus both to the pointed anterior part and to the depression behind it.

Ossification.—The tibia is ossified from three centres (figs. 449, 451, 452): one for the shaft and one for each end. Ossification begins in the middle of the shaft about the seventh week of intrauterine life. The centre for the upper end is usually present at birth, and from it a thin tongue-shaped process extends downwards in front to form the tuberosity (fig. 452); the centre for the lower end appears in the latter half of the first year. The lower end joins the shaft about the eighteenth year, the upper about the twentieth year. An additional centre for the tongue-shaped process which forms the tuberosity is not uncommon; it appears about the twelfth year and soon fuses with the upper epiphysis. The medial malleolus is usually formed by a downward extension from the lower epiphysis, commencing in the seventh year; it occasionally possesses a separate centre of ossification.

THE FIBULA (figs. 448-451)

General features.—The **fibula** is the lateral bone of the leg, and is very slender as compared with the tibia, for it is not called upon to share in the transmission of the body-weight. It possesses an upper end or head, a shaft and a lower end, which constitutes the lateral malleolus. The shaft shows considerable variation in its form, for it is moulded by the muscles to which it gives attachment; and these variations may prove confusing to the junior student. The *lower end* should be identified first. It is expanded antero-posteriorly but is flattened from side to side. It bears a triangular articular facet on the anterior part of its *medial surface*, which is directed medially to articulate with the talus. A well-marked depression, termed the

FIG. 453.—A transverse section through the right tibia and fibula, showing the attachment of the crural interosseous membrane. Upper aspect.



malleolar fossa, lies *posterior* to the articular facet. The student has now been provided with sufficient information to enable him to determine the side to which a given fibula belongs.

The **head** of the fibula is slightly expanded in all its diameters, and projects beyond the shaft in front, behind and on the lateral side. It bears on its upper surface a nearly circular articular facet, which articulates with the inferior surface of the lateral condyle of the tibia; it faces upwards, and slightly forwards and medially. A blunt elevation, termed the *apex of the head (styloid process)*, projects upwards from the lateral part of its posterior surface. The head of the fibula can be felt through the skin on the posterolateral aspect of the knee, *nearly 2 cm below the level of the knee-joint*. Immediately below the head a large nerve, termed the common peroneal (lateral popliteal) nerve, crosses the posterolateral aspect of the constricted upper end of the shaft and can be rolled against the bone in the living subject. If sufficient pressure is exerted, tingling sensations will be experienced on the dorsum

of the foot, radiating to the toes, and especially to the medial side of the big toe.

The **lower end** or **lateral malleolus** projects downwards to a lower level than the tibia and lies on a more posterior plane. Its lateral surface is subcutaneous and can be felt through the skin without difficulty; its posterior surface is marked by a broad groove with a prominent lateral border. Its anterior surface is rough and rounded and is continuous below with the inferior border. The medial surface presents a triangular articular facet, with its apex pointing downwards (fig. 454). It articulates with the lateral surface of the talus in the ankle-joint, and is convex from above downwards. Behind the articular facet the bone is marked by a roughened depression, termed the *malleolar fossa*, which readily admits the tip of a finger.

The **shaft** of the fibula (figs. 448, 450) possesses three borders and three surfaces, each of which can be associated with a particular group of muscles. The borders are anterior, posterior and interosseous, and they should be identified first. At its lower end the *anterior border* commences at the apex of an elongated, triangular area which is continuous below with the lateral surface of the lateral malleolus. Traced upwards, it ascends to reach the anterior aspect of the head. The *posterior border* is continuous with the medial margin of the groove on the back of the lateral malleolus. Usually sharp and distinct in its lower part, it is often rounded in the upper half of its extent. The *interosseous border* lies to the medial side of the anterior border and as a rule is on a more posterior plane (fig. 453), but in the upper two-thirds of the bone these two borders are very close to each other, and the intervening surface may be reduced to 1 mm. or less in width.

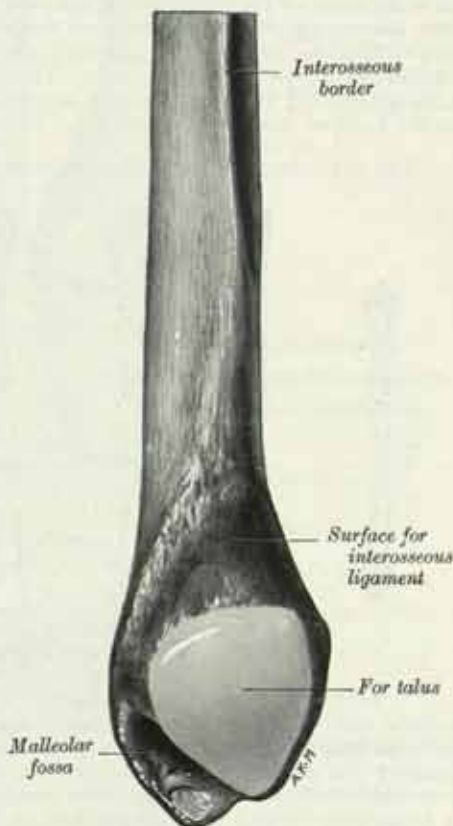
The *lateral surface* is bounded by the anterior and posterior borders. It is associated with the peroneal muscles, and is directed laterally in its upper three-fourths. Its lower fourth inclines backwards and becomes continuous with the groove on the back of the lateral malleolus. The *medial surface* (*anterior surface*) is bounded by the anterior and the interosseous borders.

It is usually directed forwards and medially, but frequently faces directly forwards. Wider below, it becomes very narrow in its upper half, and may be reduced to little more than a rounded ridge. It is associated with the extensor muscles of the leg. The *posterior surface* is the largest of the three and is placed between the interosseous and the posterior borders. It is associated with the flexor muscles of the leg. In its upper two-thirds it is divided into two areas by a longitudinal ridge, termed the *medial crest*, which is separated from the interosseous border by a grooved surface, directed medially. The rest of the posterior surface faces backwards in its upper half or more, but its lower part curves round on to the medial aspect and faces medially. The lower part of this area fits into the fibular notch on the tibia and is roughened for the attachment of the interosseous tibiofibular ligament.

The elongated, triangular area immediately above the lateral surface of the lateral malleolus (fig. 448) is subcutaneous, but the rest of the shaft is covered with muscles and cannot be examined satisfactorily in the living subject.

Particular features.—The *head of the fibula* affords origin to fibres of the extensor digitorum longus in front, peroneus longus anterolaterally, and soleus behind. The

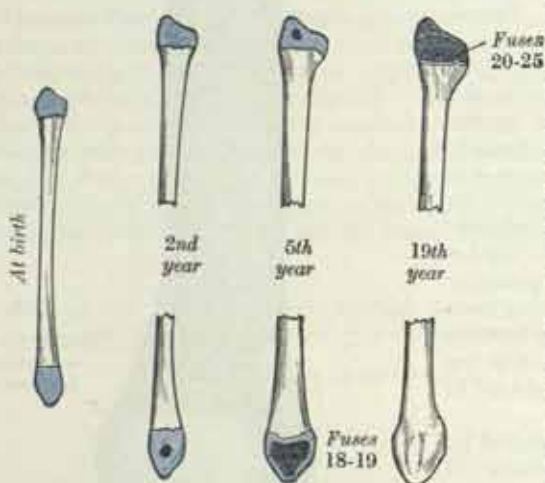
FIG. 454.—The lower end of the left fibula. Medial aspect.



tendon of biceps femoris gains its principal insertion into the anterolateral, sloping surface of the apex, but it is split near its insertion by the lower part of the fibular collateral ligament of the knee-joint, and its smaller anterior part passes into the lateral aspect of the head, above the origin of the peroneus longus. A flattened impression on the lateral aspect of the head receives the lower attachment of the fibular collateral ligament of the knee joint. The margins of the articular facet provide attachment for the capsular ligament of the tibiofibular articulation.

The *anterior border* of the fibula divides inferiorly into two ridges which enclose between them a subcutaneous triangular surface (fig. 448). The anterior intermuscular septum of the leg is attached to its upper three-fourths, and the lateral extremity of the superior extensor retinaculum to the lower part of the anterior border of the triangular area. The lower part of the posterior margin of the triangular area gives attachment to the lateral extremity of the superior peroneal retinaculum. The *interosseous border* terminates below at the upper extremity of the roughened area for the attachment of the interosseous ligament of the tibiofibular syndesmosis. It provides attachment for the interosseous membrane and does not reach so high as the head of the bone, on account of the gap in the upper part of the membrane for the transmission of the anterior tibial vessels. The *posterior border* is not always recognisable at its upper end; below, it becomes continuous with the medial border of the groove on the back of the lateral malleolus. Except at its lower end it gives attachment

FIG. 455.—Stages in the ossification of the fibula.



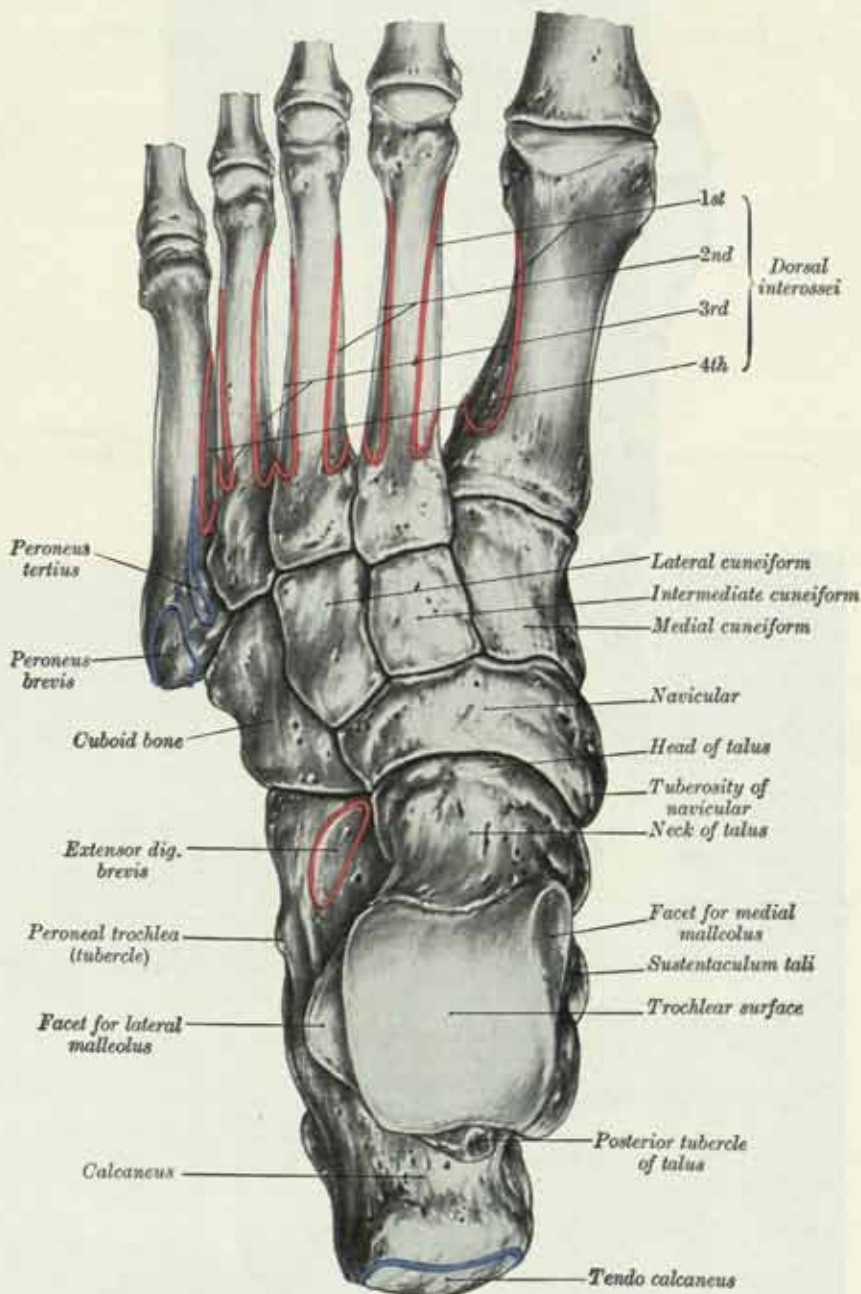
to the posterior intermuscular septum of the leg. The *medial crest* of the bone is intimately related to the peroneal artery, and the nutrient foramen of the fibula is situated either on the crest or in its immediate vicinity near the middle of the shaft. It gives attachment to a layer of the deep fascia of the leg which separates the tibialis posterior from the flexor hallucis longus and the flexor digitorum longus muscles.

The *medial surface* (*anterior surface*) of the fibula is often termed the *extensor surface*, for it gives origin to the extensor digitorum longus, the extensor hallucis longus and the peroneus tertius. The extensor digitorum longus arises from the whole breadth of the upper fourth of the

surface and from the anterior part of the succeeding two-fourths; the extensor hallucis longus arises from its middle two-fourths behind the extensor digitorum longus; the peroneus tertius arises from its lower fourth or more, and is directly continuous with the lower part of the extensor digitorum longus. The *lateral surface* is frequently termed the *peroneal surface*, because it gives origin to the peroneus longus and the peroneus brevis. The peroneus longus arises from the whole extent of the upper third of the surface and from the posterior part of the middle third. The peroneus brevis arises in front of the lower half of the peroneus longus and extends downwards beyond it almost to the lower end of the bone. On account of the relative attachments of their fleshy bellies the tendon of the peroneus brevis is closely applied to the bone below and separates it from the tendon of the peroneus longus. The *posterior surface*, which is divided longitudinally into two parts by the medial crest, is often termed the *flexor surface*. The portion which lies between the crest and the interosseous border is slightly hollowed out and gives origin to the tibialis posterior; it is often crossed by an oblique ridge which gives attachment to an intramuscular tendon. This part of the surface is usually confined to the upper three-fourths of the shaft, and at its lower end the medial crest becomes confluent with the interosseous border. The portion of the posterior surface which lies between the medial crest and the posterior border gives origin in its upper fourth to the soleus, which extends upwards on to the posterior aspect of the head; near the upper end of the medial part of this origin a roughened tubercle marks the lateral end of the tendinous arch which is thrown across the posterior tibial vessels and nerve by the soleus muscle. Below the origin of the soleus the remainder of this surface gives origin to the flexor hallucis longus, whose origin extends downwards almost to the lower end of the bone. A little above the middle of the bone, this surface is pierced by the nutrient foramen,

which is directed downwards* and transmits a branch from the peroneal artery. The triangular area of the shaft above the lateral malleolus is covered only by the superficial fascia and the skin. Above the lateral malleolus a triangular area on the medial surface

FIG. 456.—The tarsus and metatarsus of the left foot. Dorsal aspect.

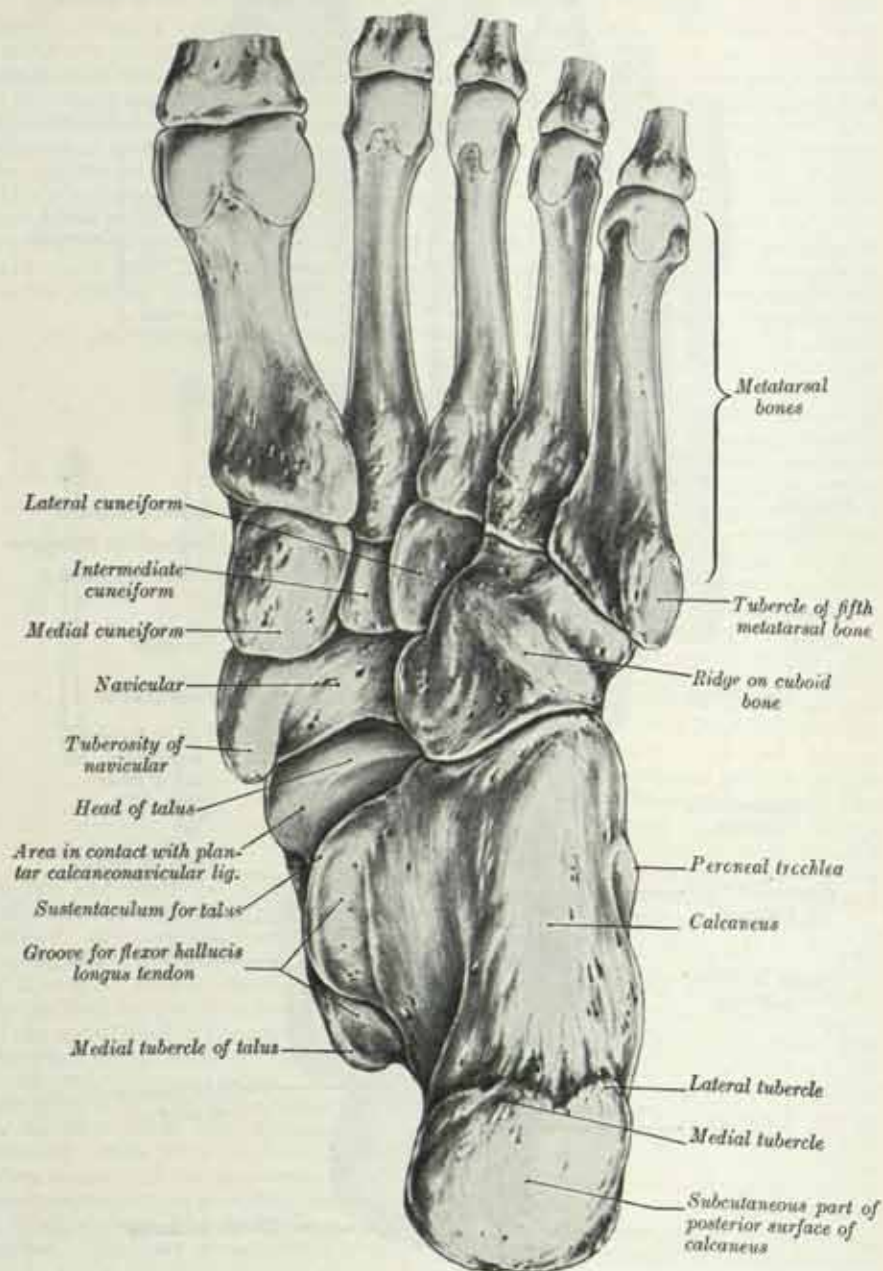


* At this point attention may be drawn to the fact that in the humerus (p. 366), the radius (p. 373), and the ulna (p. 379) the nutrient foramina are directed *towards the elbow*, whereas in the femur (p. 415), the tibia (p. 424), and the fibula they are directed *away from the knee*. The directions of these foramina, and therefore of the vessels transmitted, are to be associated with the facts that, in the upper limb, growth persists longer at the shoulder and wrist than it does in the region of the elbow, whereas in the lower limb it persists longer in the region of the knee than it does at the hip and at the ankle. In general, the direction of the nutrient foramen in all long bones is determined by the relative times of fusion of the epiphyses with the shaft, and it is always directed away from the epiphysis at which growth is more prolonged.

of the shaft gives attachment to the interosseous ligament of the tibiofibular syndesmosis (fig. 454) and its anterior and posterior margins to the corresponding ligaments of the joint.

The anterior surface of the *lateral malleolus* gives attachment to the anterior talo-fibular ligament. The lower border is marked in front by a slight notch and behind by

FIG. 457.—The tarsus and metatarsus of the left foot. Plantar aspect.



a small projection which constitutes the apex of the malleolus. It is to the notch that the calcaneofibular ligament is attached. The groove on the posterior aspect lodges the tendons of the peroneus brevis and peroneus longus; the latter is the more superficial and is closely covered by the superior peroneal retinaculum. The *malleolar fossa* (fig. 454) is pitted by numerous small vascular foramina; its upper part gives attachment to the posterior tibiofibular ligament, its lower part to the posterior talo-fibular ligament.

PLATE XVII



FIG. 1.—Radiograph of the ankle of a child aged 10 years. Note that the inferior epiphyseal line of the fibula is opposite the ankle-joint.



FIG. 2.—Radiograph of an adult foot, taken with the heel raised from the ground.

1 = tuberosity of navicular bone, partly obscured by the shadow of the head of the talus. 2 = cuneo-navicular joint. 3 = joint between metatarsal III and the lateral cuneiform bone. 4 = joint between metatarsal II and the intermediate cuneiform bone. 5 = joint between metatarsal I and the medial cuneiform bone.

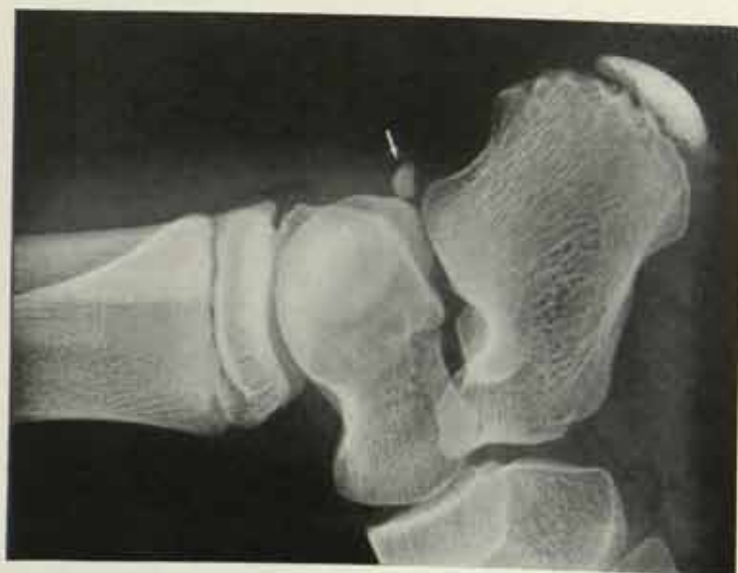


FIG. 1.—Radiograph of the ankle region of a child of 10. Note the presence of the posterior epiphysis of the calcaneum. The arrow points to the os trigonum.

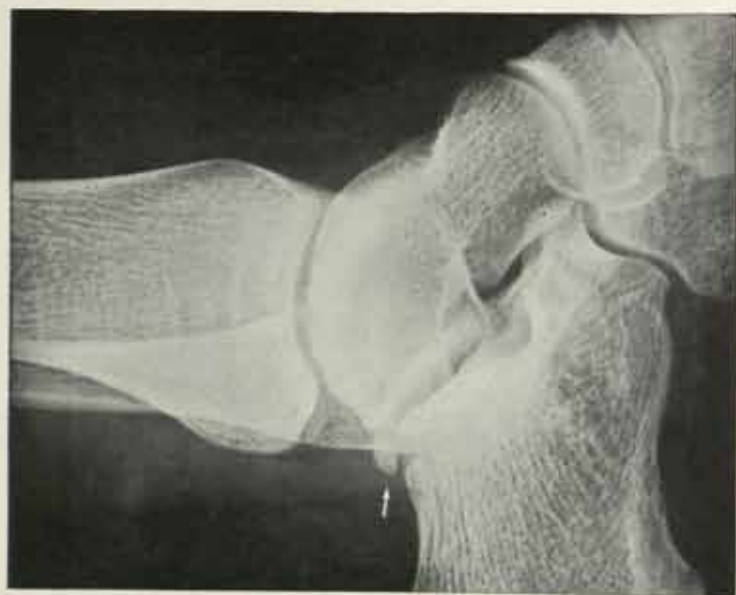
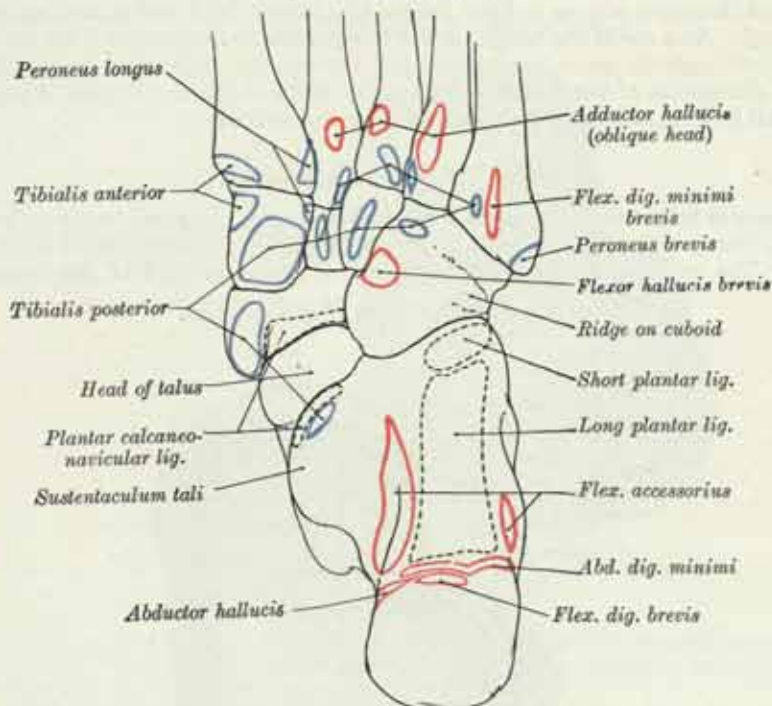


FIG. 2.—Radiograph of the ankle of an adult subject. The arrow points to the os trigonum. Note that the foot is in the position of full plantar flexion and that the long axis of the calcaneum is therefore horizontal.

Ossification.—The fibula is ossified from three centres (fig. 455): one for the shaft, and one for each end. Ossification begins in the shaft about the eighth week of intrauterine life, in the lower end early in the second year, and in the upper about the end of the fifth year. The lower epiphysis—the first to ossify—unites with the

FIG. 458.—Key to fig. 457.



shaft about the eighteenth or nineteenth year, whereas the upper epiphysis, which does not begin to ossify until later, does not unite with the shaft until about the twenty-fifth year. In this respect the fibula is peculiar in its ossification.

THE SKELETON OF THE FOOT

The skeleton of the foot has three segments: the tarsal bones, the metatarsal bones, and the phalanges or bones of the digits. In the description which follows use will be made of the terms *plantar* and *dorsal*, which are self-explanatory, and this will obviate, almost entirely, the employment of the terms anterior and posterior. Further, the terms proximal and distal will be employed, wherever reasonable, with the same significance with which they were used in the hand. Reference to the rotation which occurs in the early stages of the development of the limbs (p. 121) will explain how it comes about that, whereas the thumb is the most lateral of the digits in the hand, the great toe is the most medial of the digits in the foot.

THE TARSUS (figs. 456-458)

The **tarsus** comprises seven short bones which make up the skeleton of the posterior half of the foot. It is homologous with the carpus but its constituent elements are larger and stronger, on account of the part they play in supporting and distributing the weight of the body in the erect attitude. Like the bones of the carpus the tarsal bones are arranged in a proximal and a distal row, but an additional element is interposed between the two rows on the medial side. The proximal row comprises the **talus** and the **calcaneus**. These two bones do not lie side by side; the talus is placed above the calcaneus, but its long axis is directed forwards, medially and downwards, so that its anterior end or head comes to lie on the medial side of the calcaneus, though at a higher level. The distal row comprises four bones, named, from the medial to the lateral side, the **medial cuneiform**, the **intermediate**

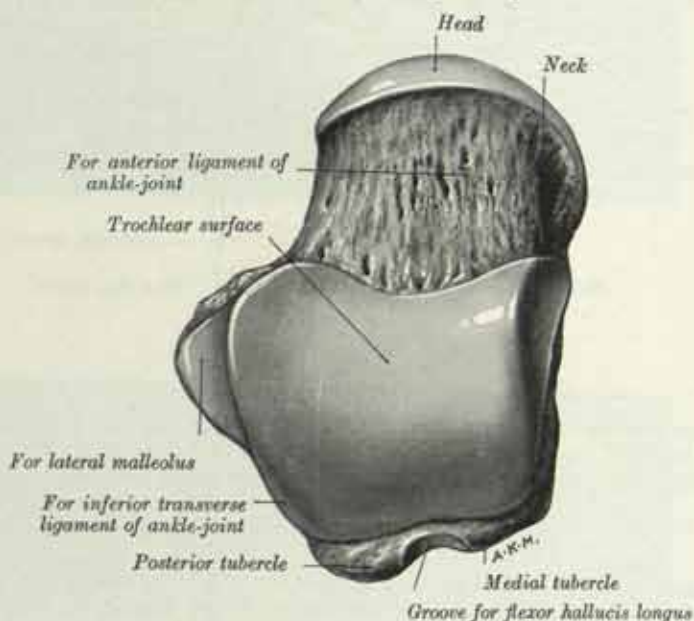
cuneiform, the **lateral cuneiform** and the **cuboid**. These bones lie side by side and together contribute to the formation of a transverse arch, which is convex dorsally. On the medial side the **navicular bone** is interposed between the talus and the medial three bones of the distal row. On the lateral side the calcaneus articulates directly with the cuboid bone.

The foot is set at right angles to the leg, and the tarsus and metatarsus are arranged in such a way as to form intersecting longitudinal and transverse arches (fig. 479). As a result the weight is not transmitted to the ground from the tibia directly through the tarsus, but is distributed through the tarsal and metatarsal bones to the extremities of the arches (see p. 543). Each of the tarsal bones is roughly cuboidal in form and presents six surfaces for examination.

THE TALUS (figs. 459-462)

General features.—The **talus** is the principal connecting link between the foot and the bones of the leg, and takes an important part in the formation of the ankle-joint. The rounded head, which is placed at the *distal* end of the bone, the

FIG. 459.—The left talus. Superior aspect.



trochlear surface for the tibia on the *dorsal* surface and the large triangular facet for the lateral malleolus on the *lateral* surface can be recognised without difficulty, and enable a talus to be referred to its appropriate side of the body.

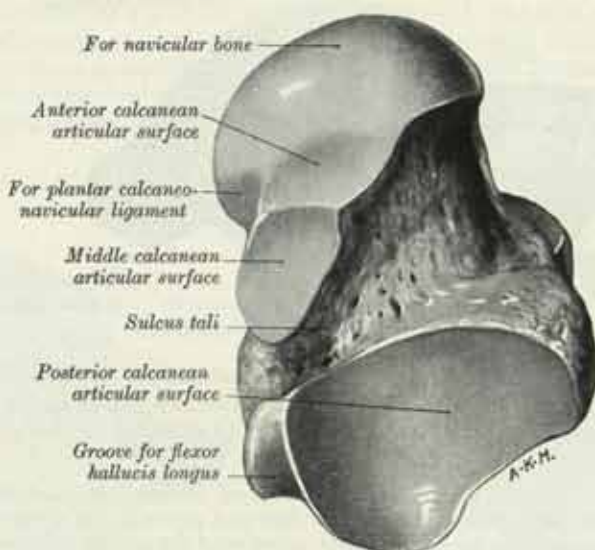
The talus possesses a head, a neck and a body.

The **head** of the talus is directed distally and slightly downwards and medially. Its *distal surface*, which is oval and convex, with its long axis directed downwards and medially, articulates with the proximal surface of the navicular bone. The *plantar surface* is marked by three articular areas, which are separated by indistinct ridges. Of these areas the most posterior is the largest: oval in outline, it is gently convex and rests on the upper surface of a shelf-like projection from the medial side of the calcaneus, named the *sustentaculum talare*. Anterior and lateral to this area, and usually continuous with it, a flattened articular facet rests in the anteromedial part of the upper surface of the calcaneus; it is continuous in front with the navicular surface. Medial to the two calcanean facets a part of the head of the talus is exposed on the plantar aspect of the articulated foot (fig. 460). This area is covered with articular cartilage and is continuous on the one hand with the calcanean areas and on the other with the navicular area. In the recent state it lies in contact with an important ligament named the *plantar calcaneonavicular* (or '*spring*') *ligament* (p. 539). When the foot is inverted passively, the dorsal and lateral part of

the head can be both seen and felt; it lies 3 cm. in front of the lower end of the tibia and becomes obscured by the extensor tendons when the toes are dorsiflexed.

The **neck** of the talus is the slightly constricted part which connects the head to the body. It is set very obliquely on the body and extends farther proximally on the medial side than on the lateral side. Its roughened surfaces give attachment to ligaments, and the medial part of its plantar surface exhibits a deep groove, termed

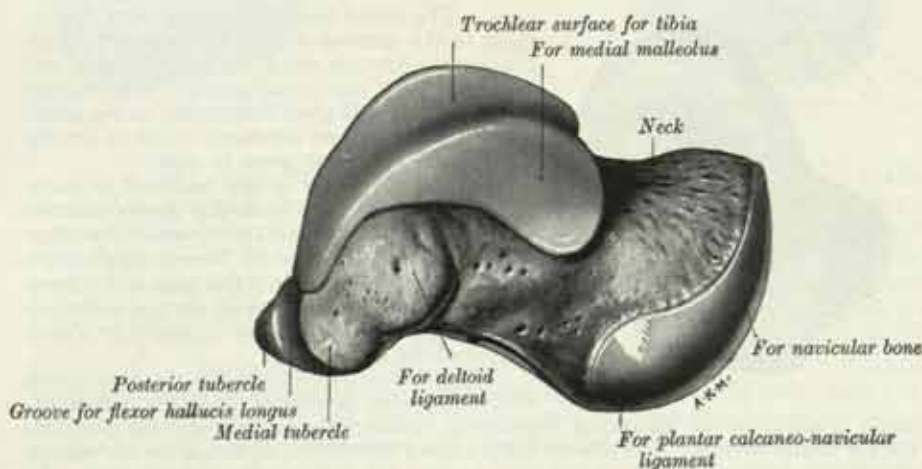
FIG. 460.—The left talus. Plantar aspect.



the *sulcus tali*. When the talus and calcaneus are articulated together this groove forms the roof of a bony canal, termed the *sinus tarsi*, which is occupied by the interosseous talocalcaneal ligament.

The **body** of the talus is cuboidal in shape. Its dorsal surface is covered by a *trochlear* articular surface, which articulates with the lower end of the tibia in the

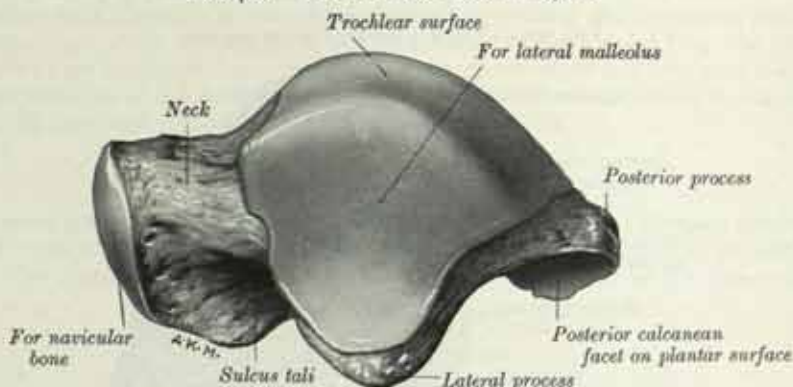
FIG. 461.—The left talus. Medial aspect.



ankle-joint. It is convex from before backwards and gently concave from side to side, and it is important to observe that it is widest anteriorly. The *lateral surface*, triangular in outline, is smooth for articulation with the lateral malleolus, and is concave from above downwards. Superiorly it is continuous with the trochlea; inferiorly its apex forms the *lateral process* of the talus. The *medial surface* is covered in its upper part by a comma-shaped articular facet which is deeper in front than behind and articulates with the medial malleolus. Below the facet the surface

is rough and is pitted by numerous vascular foramina. The *posterior surface* is rough, is small in extent and projects to form the *posterior process* of the bone. It is marked by an oblique groove placed between the two tubercles. The *lateral tubercle*, which is usually the larger, is on the lateral side of the groove; the *medial*

FIG. 462.—The left talus. Lateral aspect.



tubercle is less prominent and lies immediately behind the sustentaculum talare of the calcaneus (fig. 457). The *plantar surface* rests on the dorsal surface of the calcaneus and is covered with an oval concave facet, the long axis of which runs distally and laterally.

Particular features.—The talus is devoid of any muscular attachments, but it provides attachment for numerous ligaments (figs. 548 and 549), as it takes part in the formation of the ankle, the subtalar (talocalcaneal) and the talocalcaneonavicular joints.

The long axis of the neck is inclined downwards and distally and medially, making an angle of about 150° with the long axis of the body. This angle is smaller

FIG. 463.—The left talus of a newly born child. Viewed from above.

Compare with fig. 459, and note the angle which the long axis of the neck makes with the long axis of the body of the bone.



(130° - 140°) in the newly-born (fig. 463), and helps to account for the inverted position of the foot in young children. The dorsal surface of the neck gives attachment distally to the dorsal talonavicular ligament and the articular capsule of the ankle-joint; the proximal part of this surface therefore lies within the capsular ligament of the joint. The lateral part of the neck gives attachment to the anterior talofibular ligament, which extends downwards along the neighbouring anterior border of the lateral surface. The inferior surface of the neck gives attachment to the interosseous talocalcaneal ligament, which is usually subdivisible into three parts (p. 536).

The *medial border of the trochlear articular surface* is straight but its *lateral border* inclines medially at its posterior part, which is often broadened and flattened to form a small elongated triangular area. It is this part of the bone which comes into contact with the posterior (inferior transverse) tibiofibular ligament in dorsiflexion of the ankle joint.

The *posterior process* receives the attachment of the posterior talofibular ligament, which extends upwards to the groove, or depression, between the process and the posterior border of the trochlea. Its plantar border gives attachment to the posterior talocalcaneal ligament. The *groove* between the two tubercles of the process lodges the tendon of the flexor hallucis longus and is continuous below and in front with the groove on the plantar surface of the sustentaculum talare. The *medial tubercle* gives attachment by its medial aspect to the medial talocalcaneal ligament below, and to the most posterior of the superficial fibres of the deltoid ligament above.

The roughened area below the comma-shaped articular facet on the medial surface provides attachment for the deep fibres of the deltoid ligament.

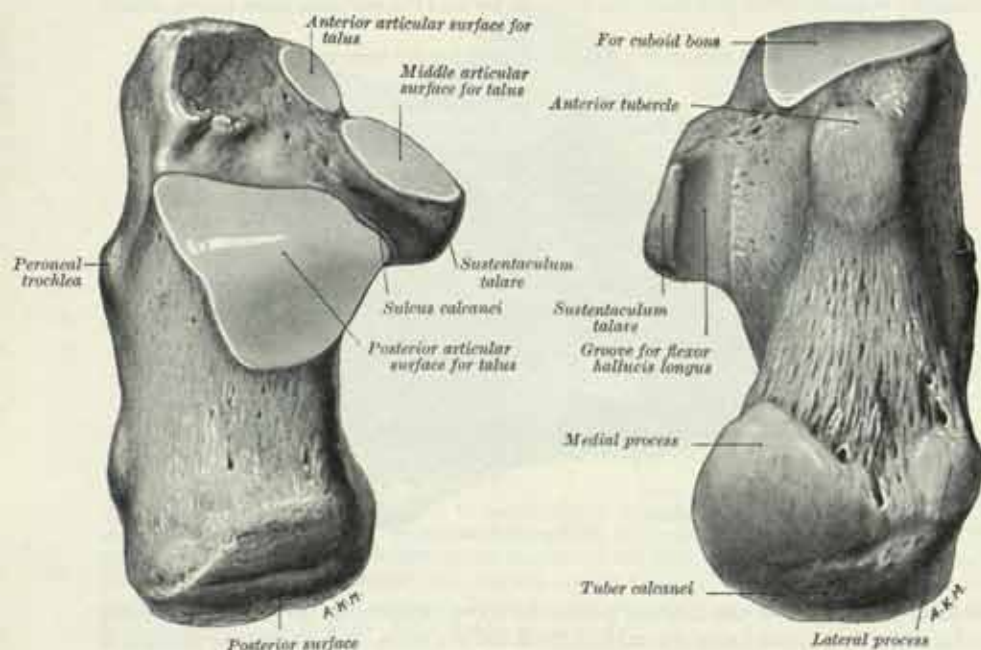
The long axis of the posterior calcaneal facet on the plantar surface of the body runs forwards and laterally at an angle of about 45° with the median plane.

THE CALCANEUS (figs. 464-467)

General features.—The **calcaneus** is the largest and strongest of the tarsal bones; it projects backwards beyond the bones of the leg so as to provide a useful lever for the muscles of the calf, which are inserted into its posterior surface. It is irregularly cuboidal in shape, and its long axis is directed forwards, upwards and somewhat laterally. The student will experience no difficulty in distinguishing the small articular anterior end from the larger, roughened, posterior end, nor in distinguishing the rough plantar surface from the dorsal surface, which bears a large, articular facet about its middle. Finally the lateral surface is flattened, whereas the medial surface is hollowed out from above downwards and backwards. The student should now be able to assign a calcaneus correctly to its appropriate side of the body.

FIG. 464.—The left calcaneus.
Dorsal aspect.

FIG. 465.—The left calcaneus.
Plantar aspect.



The dorsal or *upper surface* is subdivisible into three areas. The posterior third is roughened, convex from side to side and concave from behind forwards; it supports a mass of fibro-fatty tissue interposed between the tendo calcaneus and the back of the ankle-joint. The middle third is covered by the *posterior facet for the talus*, which is oval in outline and convex anteroposteriorly. The anterior third is partly articular and partly non-articular. In front of the posterior articular facet there is a rough depression, which becomes narrower and takes the form of a groove on the medial side. This is termed the *sulcus calcanei* or *groove of the calcaneus*; it corresponds to the sulcus tali and helps it to complete the sinus tarsi in the articulated foot. In front of and medial to this groove an elongated articular area covers the dorsal surface of a projecting shelf termed the *sustentaculum talare*, and extends forwards and medially on to the body of the bone. This area is not infrequently subdivided into two parts by a narrow non-articular interval which marks the anterior limit of the sustentaculum talare. They constitute the *middle* and *anterior facets for the talus*.

The *anterior surface* is the smallest of the six surfaces, and is entirely covered by an obliquely-set concavoconvex facet which articulates with the cuboid bone.

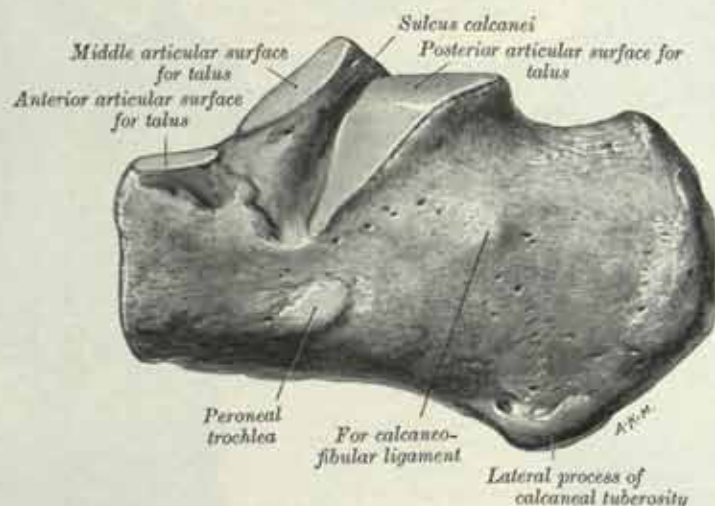
The *posterior surface* is divided into three areas. The uppermost is smooth and is separated from the tendo calcaneus by a bursa and some fatty tissue. The middle area is the largest; it is roughened to give insertion to the tendo calcaneus. The lowest area slopes downwards and forwards and is subcutaneous.

The *plantar surface* is rough, especially at its posterior end, where it is marked by the *calcaneal tuberosity*. The *lateral* and *medial processes* of the tuberosity extend distally for a short distance, separated by an indistinct notch. The medial process is the broader of the two (fig. 465). More distally a tubercle marks the distal limit of the attachment of the long plantar ligament.

The *lateral surface* is almost flat and is much deeper behind than in front; it can be palpated on the lateral aspect of the heel and can be traced forwards below the lateral malleolus. In its anterior part it presents a small elevation, termed the *peroneal trochlea* (tubercle) (fig. 464), which is exceedingly variable in its size, and when well developed, can be felt in the living subject 2 cm. below the tip of the lateral malleolus. It exhibits an oblique groove on its postero-inferior part, for the peroneus longus tendon, and a shallower groove on its anterosuperior aspect, for the peroneus brevis tendon. About 1 cm. or more behind the peroneal trochlea a second elevation may mark the bone; it gives attachment to the calcaneofibular part of the lateral ligament of the ankle-joint.

The *medial surface* is concave from above, downwards and backwards, and its concavity is accentuated by a shelf-like process, termed the *sustentaculum talare*, which

FIG. 466.—The left calcaneus. Lateral aspect.



projects medially from the anterior part of its upper border (fig. 467). The superior surface of this process bears the middle facet for the talus, and its inferior surface is marked by a groove which is continuous with the groove on the posterior surface of the talus and lodges the flexor hallucis longus tendon (fig. 465). The medial surface of the sustentaculum talare, can be felt indistinctly through the skin immediately below the tip of the medial malleolus; occasionally it presents a groove for the flexor digitorum longus tendon.

Particular features.—The *groove of the calcaneus* gives attachment to the interosseous talocalcaneal ligament (p. 536). In addition, the non-articular area in front of the posterior facet for the talus gives partial origin to the extensor digitorum brevis and attachment to the principal band of the inferior extensor retinaculum and to the stem of the bifurcated ligament.

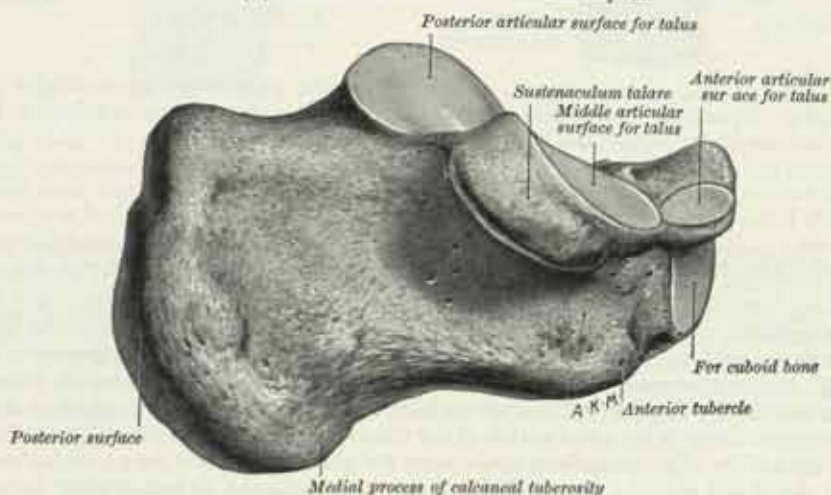
The *medial process of the tuberosity* gives origin by its prominent medial margin to the abductor hallucis (fig. 458) and attachment to the superficial part of the flexor retinaculum, and in front to the plantar aponeurosis and the flexor digitorum brevis. The *lateral process* gives origin to the abductor digiti minimi, which extends medially to arise from the front of the medial process also. The roughened strip between the two processes, proximally, and the tubercle, distally, gives attachment to the long plantar ligament, while the short plantar ligament springs from the tubercle and the narrow rough area distal to it (fig. 458). The lateral tendinous head of the flexor digitorum accessorius arises from the bone in front of the lateral process close to the lateral margin of the long plantar ligament.

The *posterior surface* is wider below than above. Close to the medial side of the insertion of the tendo calcaneus it receives the insertion of the plantaris muscle.

The anterior part of the *lateral surface* is crossed by the peroneal tendons, but in most of its extent is covered only by the skin and superficial fascia. The peroneus brevis tendon, after passing behind the lateral malleolus, runs forwards and slightly downwards above and in front of the peroneal trochlea; the peroneus longus tendon passes downwards and forwards below and behind the trochlea, which gives attachment to a slip from the inferior peroneal retinaculum (p. 685). The calcaneofibular ligament is attached to the bone about 1 cm. behind the peroneal trochlea, and the site is usually indicated by a low rounded elevation.

The *sustentaculum talare* assists, by its dorsal surface, in the formation of the talocalcaneonavicular joint; its plantar surface is grooved by the flexor hallucis longus tendon, and the margins of the groove give attachment to the deep part of the flexor retinaculum. The medial margin of the process is a narrow roughened strip, convex from before backwards. Anteriorly it gives attachment to the plantar calcaneonavicular (or 'spring') ligament (p. 539); behind that it gives attachment to a slip from

FIG. 467.—The left calcaneum. Medial aspect.



the tibialis posterior tendon and to some of the superficial fibres of the deltoid ligament; its posterior part receives the medial talocalcaneal ligament. Below the attachment of the deltoid ligament the tendon of the flexor digitorum longus is related to this aspect of the process and sometimes its position is indicated by a groove. Below the groove for the flexor hallucis longus the medial surface gives origin to the large, fleshy, medial head of the flexor accessorius.

THE NAVICULAR BONE (fig. 468)

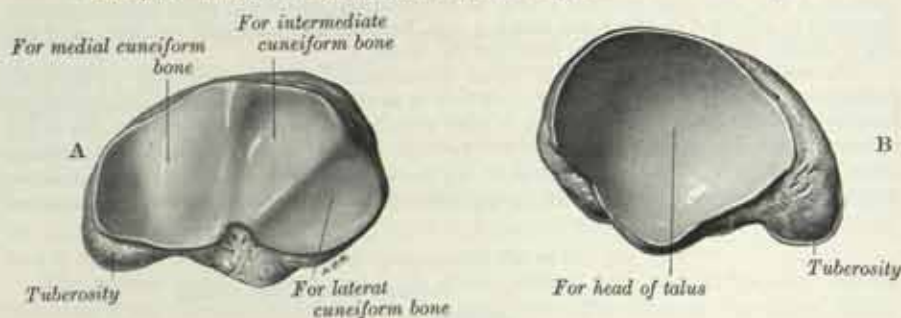
The **navicular bone** is interposed between the head of the talus proximally and the cuneiform bones distally.

The *distal surface* is convex from side to side and is subdivided into three facets (of which the most medial is the largest) for articulation with the three cuneiform bones. The *proximal surface*, oval and concave, articulates with the head of the talus. The *dorsal surface* is roughened and is convex from side to side. The *medial surface* also is rough and is continued downwards to form a prominent projection termed the *tuberosity*. It can be felt through the skin about 2.5 cm. below and in front of the medial malleolus. The *plantar surface*, also roughened, is concave, and is separated from the tuberosity on the medial side by a groove. The *lateral surface* is rough and irregular, but frequently presents a facet for articulation with the cuboid bone.

Particular features.—The facet for the medial cuneiform is triangular in outline, with its rounded apex on the medial side. The facets for the intermediate and lateral cuneiform bones are also triangular, but their apices point towards the sole. The dorsal surface gives attachment to the dorsal talonavicular, cuneonavicular, and cubonavicular ligaments. The *tuberosity* of the navicular bone provides the principal insertion for the tibialis posterior tendon, and the groove which lies on its lateral side

transmits the part of this tendon which runs forwards to reach the cuneiform bones and the bases of the middle three metatarsal bones. A slight projection marks the plantar surface of the bone on the lateral side of the groove. Together with the proxi-

FIG. 468.—The left navicular bone. A. Distal aspect. B. Proximal aspect.



mal part of this surface it gives attachment to the plantar calcaneonavicular (or 'spring') ligament. The roughened part of the lateral surface gives attachment to the calcaneonavicular part of the bifurcated ligament.

THE CUNEIFORM BONES (figs. 469-471)

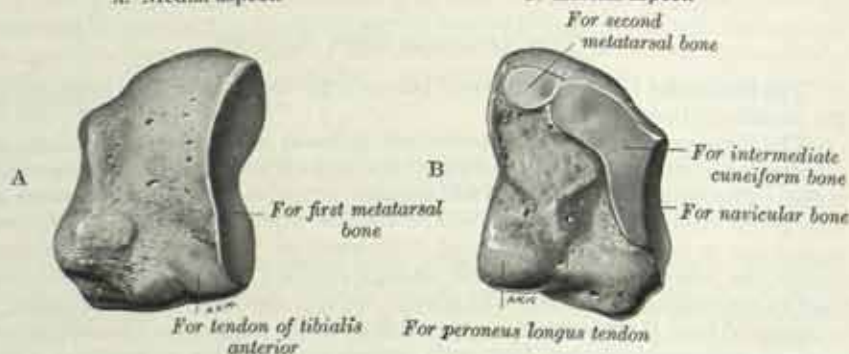
The **cuneiform bones**, three in number, are wedge-shaped and articulate with the navicular bone proximally and the bases of the first, second and third metatarsal bones distally. The medial cuneiform bone is the largest of the three, and the intermediate the smallest. In the intermediate and in the lateral cuneiform bone the dorsal surface is the base of the wedge and the plantar surface represents the edge, but in the medial cuneiform bone the wedge is reversed so that its edge is represented by the narrow, dorsal surface of the bone. This arrangement is an important factor in the constitution of the transverse arch of the foot. The proximal surfaces of the three cuneiform bones form a slight concavity for the navicular bone, but the distal parts of the medial and lateral cuneiforms project distally beyond the intermediate cuneiform bone, and bound a deep recess in which the base of the second metatarsal bone is lodged (fig. 458).

Particular features.—The **medial cuneiform bone** (fig. 469) is the most medial bone of the distal row of the tarsus; it articulates with the navicular bone proximally

FIG. 469.—The left medial cuneiform bone.

A. Medial aspect.

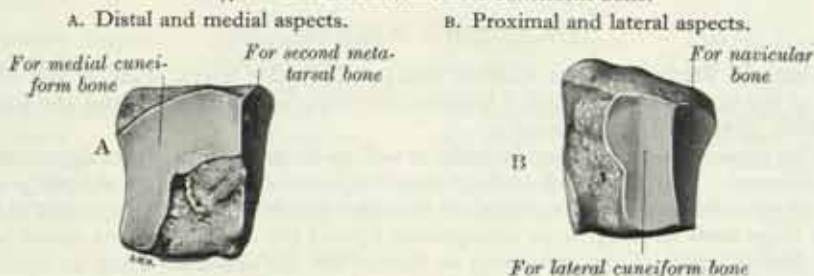
B. Lateral aspect.



and with the base of the first metatarsal bone distally. The *dorsal surface* is rough and narrow, and represents the edge of the wedge. The *plantar surface* represents the base of the wedge; it receives a substantial slip from the tendon of the tibialis posterior muscle. The *distal surface* bears a large kidney-shaped facet for articulation with the base of the first metatarsal bone, and the little notch which represents the hilus lies on its lateral margin. The *proximal surface* bears a piriform facet, which articulates with the navicular bone. Concave in its vertical axis, it is narrower at its dorsal than

at its plantar end. The *medial surface* is rough and subcutaneous. It is slightly convex in its vertical axis and its distal-plantar angle is marked by a large, flattened impression which receives the insertion of most of the fibres of the tibialis anterior tendon (fig. 469 A). The *lateral surface* is partly articular and partly non-articular. Along its proximal and dorsal margins it is covered with an Γ -shaped smooth strip which articulates with the intermediate cuneiform bone. The dorsal and distal part of this strip is separated by a vertical ridge from a small, almost square, facet which articulates with the dorsal part of the medial surface of the base of the second meta-

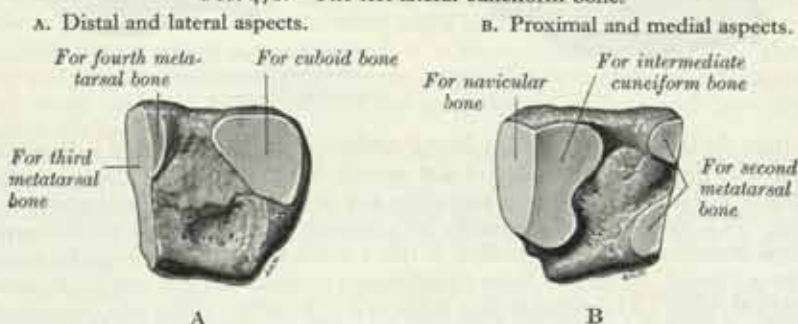
FIG. 470.—The left intermediate cuneiform bone.



tarsal bone. Below this facet the bone is attached to the medial side of the base of the second metatarsal bone by a strong interosseous ligament, and proximally the interosseous intercuneiform ligament connects it to the medial side of the intermediate cuneiform bone. The distal and plantar part of the lateral surface is roughened where it receives the insertion of part of the peroneus longus tendon (fig. 469 B).

The **intermediate cuneiform bone** (fig. 470) articulates distally with the base of the second metatarsal and proximally with the navicular bone. It is of very regular wedge-like form, the base of the wedge forming the roughened, *dorsal surface*, and the edge the narrow, *plantar surface*, which receives a slip from the tibialis posterior tendon. The *distal* and *proximal surfaces* are covered each with a triangular articular facet, for the base of the second metatarsal and the navicular bone respectively. The *medial surface* is partly articular and partly non-articular. Along its proximal and

FIG. 471.—The left lateral cuneiform bone.



dorsal margins it bears a Γ -shaped strip, occasionally subdivided into two parts, for articulation with the medial cuneiform. The *lateral surface* also is partly articular and partly non-articular. Along its proximal margin it bears a vertical strip, usually indented at its middle, for articulation with the lateral cuneiform bone. Strong interosseous ligaments connect the non-articular parts of the lateral and medial surfaces to the lateral and medial cuneiform bones, respectively.

The **lateral cuneiform bone** (fig. 471) is placed between the intermediate cuneiform and the cuboid bones. Distally it articulates with the base of the third metatarsal and proximally with the navicular bone. Like the intermediate cuneiform, its *dorsal surface*, rough and almost rectangular, represents the base of the wedge, and its *plantar surface*, narrow and rough, the edge. The latter receives a slip from the tibialis posterior tendon and may give partial origin to the flexor hallucis brevis. The *distal surface* is completely covered with a triangular articular facet for the base of the third metatarsal bone. The *proximal surface* is rough in its plantar part but is smooth and articular in its dorsal two-thirds, which articulate with the navicular by means of a triangular facet. The *medial surface* is partly articular and partly non-articular. Along its proximal margin it bears a vertical strip, indented at its middle,

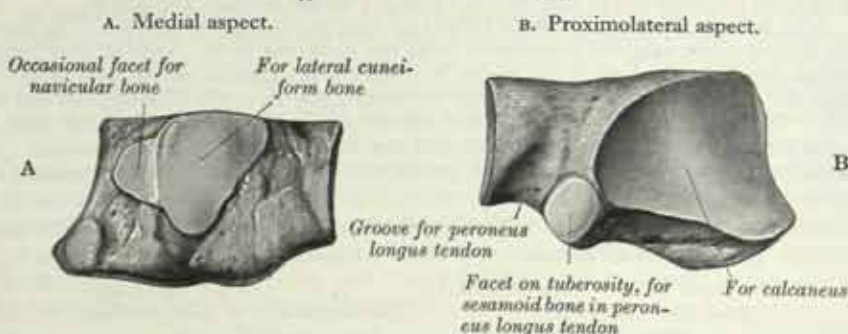
for the intermediate cuneiform bone, and along its distal margin a narrower strip, often divided into two small facets, serves for articulation with the lateral aspect of the base of the second metatarsal bone. The *lateral surface* also is partly articular and partly non-articular. A large triangular or oval facet is situated proximally for articulation with the cuboid bone; a small facet, semi-oval in shape, is placed at the dorsal part of its distal margin for articulation with the dorsal part of the medial side of the base of the fourth metatarsal bone. The non-articular portions of the medial and lateral surfaces give attachment to strong intercuneiform and cuneocuboid ligaments, which play an important part in maintaining the transverse arch of the foot.

THE CUBOID BONE (fig. 472)

General features.—The **cuboid bone** is the most lateral bone of the distal row of the tarsus, and is situated between the calcaneus proximally and the fourth and fifth metatarsal bones distally.

The *dorsal surface*, directed laterally as well as dorsally, is rough for ligamentous attachments. The distal part of the *plantar surface* is crossed by an oblique *groove for the peroneus longus tendon*, which is bounded proximally by a prominent ridge. This ridge ends laterally in an enlargement termed the *tuberosity of the cuboid bone*. The lateral aspect of the tuberosity is faceted for the sesamoid bone or cartilage which is frequently found in the peroneus longus tendon. Proximal to the ridge the plantar surface is rough and, owing to the obliquity of the calcaneocuboid joint, extends proximally and medially so that the medial border of this surface is much

FIG. 472.—The left cuboid bone.



longer than the lateral border. The *lateral surface* is rough and exhibits a deep notch which marks the commencement of the groove for the peroneus longus tendon. The *medial surface* is much more extensive and is partly articular and partly non-articular. It is marked near its middle by a smooth oval facet for articulation with the lateral cuneiform bone; proximal to this a small facet for the navicular bone is sometimes present. The two form a continuous articular surface but are separated by a vertical ridge. The *distal surface* is divided by a vertical ridge into two articular areas; the medial facet is quadrilateral in form and articulates with the base of the fourth metatarsal bone; the lateral facet, triangular in outline with the apex on the lateral side, articulates with the base of the fifth metatarsal bone. The *proximal surface*—smooth, triangular and concavoconvex—articulates with the distal surface of the calcaneus; its medial plantar angle projects proximally as a process which helps to support the distal end of the calcaneus.

Particular features.—The dorsal surface gives attachment to the dorsal calcaneocuboid, cubonavicular, cuneocuboid and cubometatarsal ligaments. The ridge on the plantar surface gives attachment to the deep fibres of the long plantar ligament, which conceals the attachment of the short plantar ligament to the proximal border of this surface. The projecting proximomedial part of the plantar surface receives a slip from the tendon of the tibialis posterior and gives origin to the flexor hallucis brevis muscle. The rough part of the medial surface of the cuboid affords attachment for the interosseous cuneocuboid and cubonavicular ligaments, and in its proximal part to the medial calcaneocuboid, which is the lateral limb of the bifurcated ligament.

The Homologies of the Carpus and the Tarsus.—In the most primitive reptiles the carpus and tarsus resemble one another very closely and, on the assumption that the

radius, which is the pre-axial bone of the forearm, is homologous with the tibia, which is the pre-axial bone of the leg—a view which is generally but not universally accepted—little difficulty is experienced in determining the homologies of their constituent elements. In man the carpus remains relatively primitive and the identification of its elements in the reptilian carpus is a comparatively simple problem. Owing to the adoption of the erect attitude the human tarsus has been modified very considerably, and it is only by reference to the primitive reptilian condition that any clue can be obtained to the homologies of the carpal and tarsal bones.

The following tabular statement presents the view which has obtained most support.*

<i>Reptilian Carpus.</i>	<i>Human Carpus.</i>	<i>Reptilian Tarsus.</i>	<i>Human Tarsus.</i>
Os radiale	Scaphoid bone (less its tubercle)	Os tibiale	Talus
Os intermediale	Lunate bone	Os intermediale	(Os trigonum)
Os ulnare	Triquetral bone	Os fibulare	Calcaneus
Ossa centralia (1 and 2)	Tubercle of the scaphoid bone	Ossa centralia (1 and 2)	Navicular bone
Os carpal 1	Trapezium bone	Os tarsale 1	Medial cuneiform bone
„ „ 2	Trapezoid bone	„ „ 2	Intermediate cuneiform bone
„ „ 3	Capitate bone	„ „ 3	Lateral cuneiform bone
„ „ 4 and 5	Hamate bone	„ „ 4 and 5	Cuboid bone

THE METATARSUS

The **metatarsal bones**, five in number, are situated in the distal part of the foot, distal to the tarsus and proximal to the phalanges. They are numbered from the medial to the lateral side.

THE COMMON CHARACTERS OF THE METATARSAL BONES

Like the metacarpals, the metatarsals are miniature long bones, and each possesses a shaft, a base or proximal end, and a head or distal end.

With the exception of the first and, to a lesser degree, the fifth, the **shafts** are long and slender, and are slightly convex longitudinally on their dorsal aspects and concave on their plantar aspects. They are prismoid in form and taper from the base to the head.

The **bases** articulate with the distal row of the tarsus and with one another. The line of each tarsometatarsal joint, excluding the first, passes proximally and laterally, and the bases of the metatarsals are therefore set somewhat obliquely relative to their shafts—a fact which assists in the recognition of the side of the body to which the bones belong.

The **heads** articulate with the proximal phalanges of their own digits, each by means of a convex articular surface which extends farther on the plantar than on the dorsal surface; the plantar extension ends on each side on the summit of a slight eminence. The sides of the heads are flattened, and each shows a depression surmounted dorsally by a tubercle, which gives attachment to one of the collateral ligaments of the metatarsophalangeal joint.

THE CHARACTERS OF THE INDIVIDUAL METATARSAL BONES

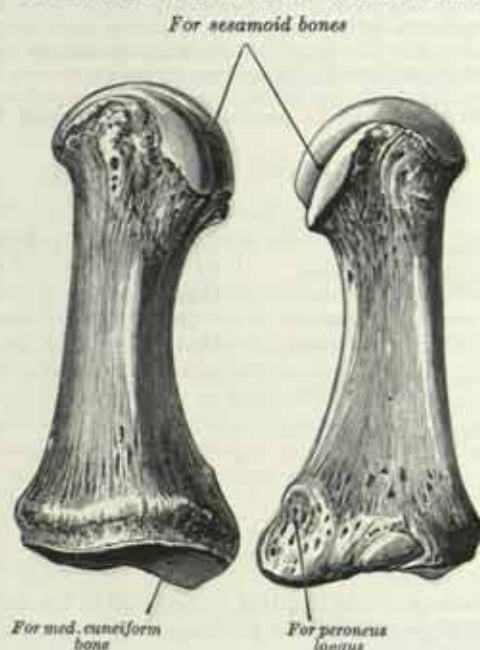
The **first metatarsal bone** (fig. 473) is the shortest and thickest of the metatarsal bones. The *body* is strong, and of well-marked prismoid form. The *base* has no articular facets on its sides, but there is occasionally a tuberosity, (really a pressure

* According to R. Broom (*The Origin of the Human Skeleton*, 1930) the ossa centralia, the os carpal 5 and the os tarsale 5 are not represented in man. His view of the homologies differs from that given above in the following particulars:

Scaphoid bone (including its tubercle) = os radiale.
Navicular bone = os tibiale.
Talus (including os trigonum) = os intermediale.
Hamate bone = os carpal 4.
Cuboid bone = os tarsale 4.

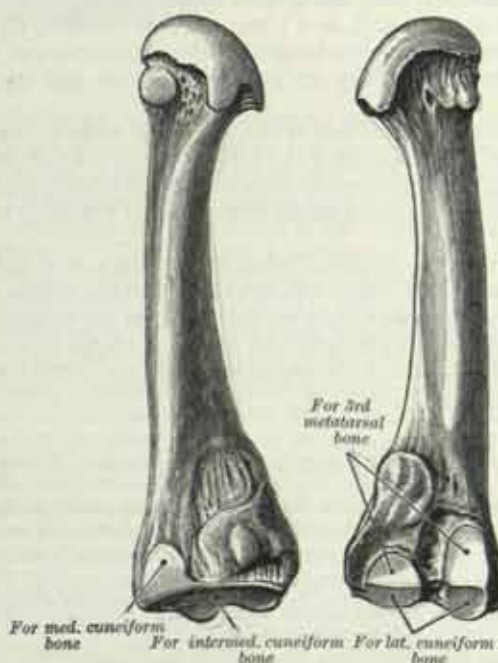
facet), on the lateral side caused by contact with the second metatarsal bone. Its proximal surface, of large size and kidney-shaped, articulates with the medial cunei-

FIG. 473.—The left first metatarsal bone. Medial and lateral aspects.



form bone ; the lateral border of the facet shows a slight indentation, which represents the hilus of the kidney. Its circumference is grooved for the tarsometatarsal ligaments,

FIG. 474.—The left second metatarsal bone. Medial and lateral aspects.



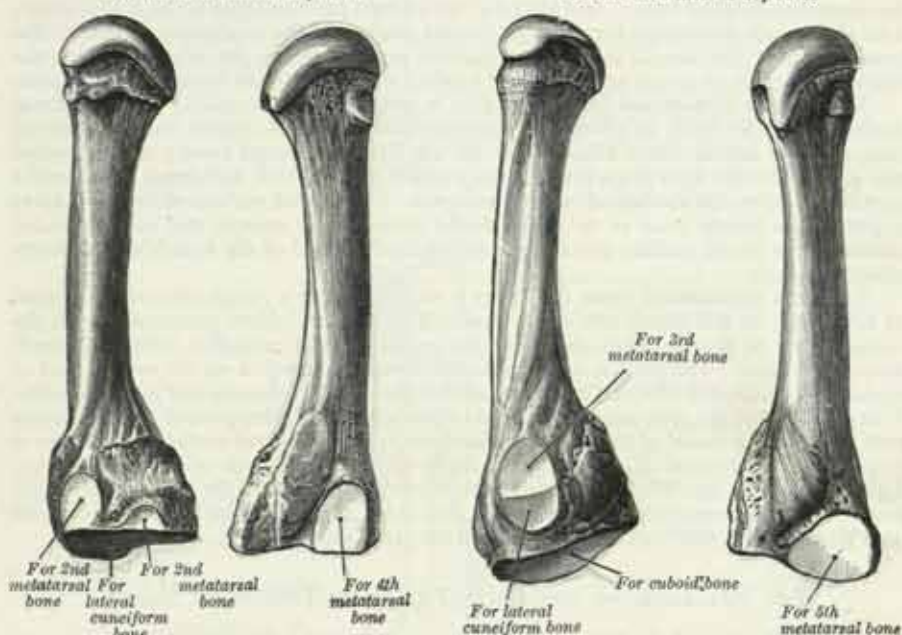
and medially gives insertion to a part of the tendon of the tibialis anterior ; its plantar angle presents a rough, oval prominence on its lateral aspect for the insertion of the tendon of the peroneus longus. The lateral surface of the shaft is flat and gives origin

to the medial head of the first dorsal interosseous muscle. The *head* is large ; on its plantar surface there is a median elevation separating two grooved facets on which sesamoid bones glide.

The **second metatarsal bone** (fig. 474) is the longest of the metatarsal bones. Its

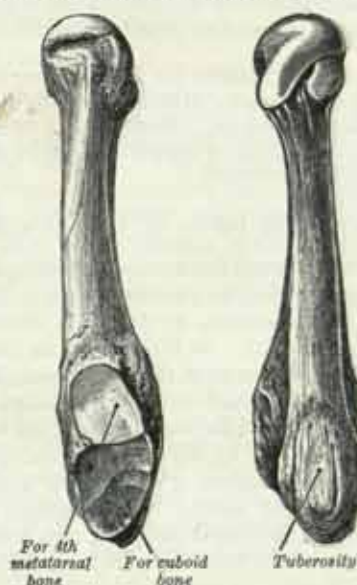
FIG. 475.—The left third metatarsal bone.
Medial and lateral aspects.

FIG. 476.—The left fourth metatarsal bone.
Medial and lateral aspects.



wedge-shaped *base* bears four articular facets : one on its proximal surface, of a triangular form, for articulation with the intermediate cuneiform bone ; one at the dorsal part of its medial surface, for articulation with the medial cuneiform bone ; and two

FIG. 477.—The left fifth metatarsal bone. Medial and lateral aspects.



on its lateral surface, a dorsal and a plantar, separated by a rough non-articular interval. Each of these lateral articular surfaces is divided by a ridge ; the distal two facets articulate with the third metatarsal bone ; the proximal two (sometimes continuous)

with the lateral cuneiform bone. A pressure facet is occasionally present caused by contact with the first metatarsal bone; it is oval in shape, and is situated on the medial side of the base, plantar to the facet for the medial cuneiform bone. The medial and lateral surfaces of the shaft give origin respectively to the lateral head of the first dorsal interosseous muscle and the medial head of the second.

The **third metatarsal bone** (fig. 475) has a triangular *base*, which articulates proximally with the lateral cuneiform bone; medially it articulates by two facets with the second metatarsal bone; and laterally, by a single facet situated at the dorsal angle, with the fourth metatarsal bone. The medial surface of the shaft gives origin to the lateral head of the second dorsal interosseous muscle and to the first plantar; the lateral surface gives origin to the medial head of the third dorsal interosseous muscle.

The **fourth metatarsal bone** (fig. 476) is smaller than the third. The proximal surface of its *base* bears an oblique quadrilateral facet for articulation with the cuboid bone; on its lateral side a single facet, for the fifth metatarsal bone; on its medial side a facet divided by a ridge into a distal portion for the third metatarsal bone, and a proximal portion for the lateral cuneiform bone. The medial surface of the shaft gives origin to the lateral head of the third dorsal interosseous muscle and to the second plantar; the lateral surface gives origin to the medial head of the fourth dorsal interosseous muscle.

The **fifth metatarsal bone** (fig. 477) is recognised by a rough eminence, termed its *tuberosity*, on the lateral side of its base. The *base* articulates proximally with the cuboid bone by a triangular, obliquely cut surface; and medially, with the fourth metatarsal bone. The tendon of the peroneus tertius is inserted on the medial part of its dorsal surface, and that of the peroneus brevis on the dorsal surface of the tuberosity. A strong band of the plantar aponeurosis connects the projecting part of the tuberosity with the lateral process of the calcaneal tuberosity. The plantar surface of the base is grooved by the tendon of the abductor digiti minimi, and gives origin to the flexor digiti minimi brevis. The medial side of the shaft gives origin to the lateral head of the fourth dorsal interosseous muscle and to the third plantar. The tuberosity can be both seen and felt, half-way along the lateral border of the foot.

THE PHALANXES OF THE FOOT [PHALANXES DIGITORUM PEDIS]

The **phalanges** of the foot correspond in number and general arrangement with those of the hand; there are two in the big toe, and three in each of the other toes. They are, however, much smaller, and their shafts, especially those of the bones of the first row, are compressed from side to side.

The **proximal phalanges** closely resemble those of the hand. The *shaft* of each is compressed from side to side, convex dorsally, concave on its plantar aspect. The *base* is concave for articulation with the head of the corresponding metatarsal bone, and the *head* possesses a trochlear surface for articulation with the middle phalanx.

The **middle phalanges** are remarkably small and short, but rather broader than the proximal phalanges.

The **distal phalanges** resemble those of the fingers; but they are smaller, and are flattened; each presents a broad base for articulation with the corresponding middle phalanx, and an expanded distal extremity. Each bears a roughened *tuberosity* on the plantar aspect of its distal end, which gives attachment to the pulp of the tip of the toe and provides a wider area to take pressure.

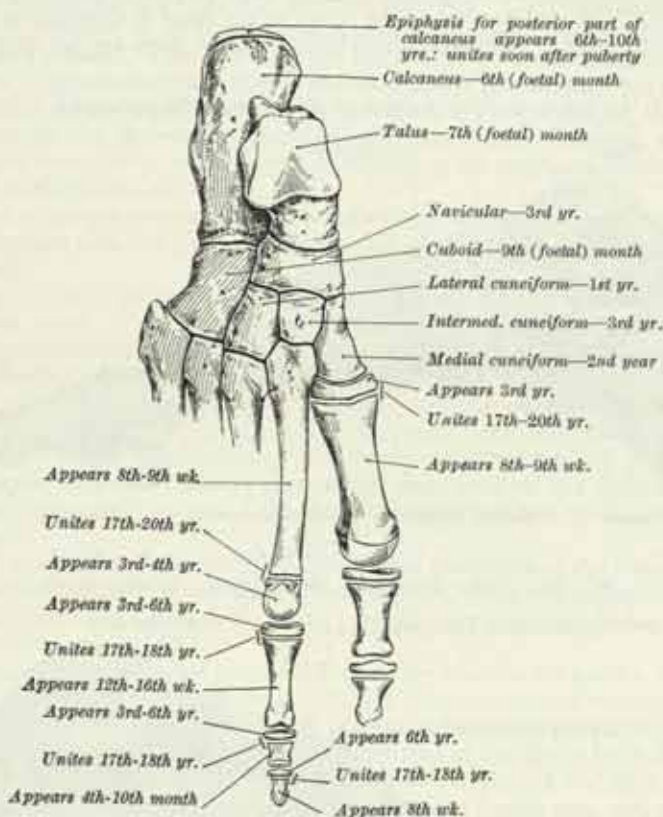
OSSIFICATION OF THE BONES OF THE FOOT (fig. 478)

The **tarsal bones** are ossified each from a single centre, excepting the calcaneus which has a scale-like epiphysis for its posterior part. The centres make their appearance as follows: in the calcaneus, at the sixth month of intrauterine life; in the talus, about the seventh month; in the cuboid, at the ninth month; in the lateral cuneiform, during the first year; in the medial cuneiform, at the end of the second year; in the intermediate cuneiform and navicular, during the third year. The epiphysis for the posterior part of the calcaneus begins to ossify at or before the tenth year, and unites with the rest of the bone soon after puberty. It may be formed from two centres of ossification, a dorsal and a plantar, which coalesce between the fifteenth and sixteenth years. The posterior process of the talus is sometimes ossified from an independent centre, and may then remain separate or it may be connected to the rest of the bone by cartilage. This additional ossicle is named the *os trigonum*.

The **metatarsal bones** are ossified each from two centres: a primary centre for the shaft, and a secondary or epiphysal centre for the base or proximal end of

the first, and for the head or distal end of each of the other four.* Ossification begins in the middle of the shaft about the eighth or ninth week of intrauterine life. The epiphysis for the base of the first metatarsal appears about the third year; those for the heads of the other metatarsals between the third and fourth years; all unite with the shafts between the seventeenth and twentieth years. An epiphysis is frequently present on the tubercle of the base of the fifth metatarsal bone (Holland).†

FIG. 478.—A plan of the ossification of the bones of the foot.



The **phalanges** are each ossified from two centres: a primary one for the shaft and an epiphysis for the base. The primary centres for the distal phalanges appear about the eighth week of intrauterine life: those for the proximal phalanges between the twelfth and sixteenth weeks, and those for the intermediate phalanges after the sixteenth week (that for the phalanx of the fifth toe does not usually appear until after birth). The epiphyseal centres appear between the third and sixth years, and unite with the shafts about the seventeenth or eighteenth year.

COMPARISON OF THE BONES OF THE HAND AND FOOT

The hand and foot are constructed on similar principles—each comprising a proximal part, the carpus or tarsus, an intermediate portion, the metacarpus or metatarsus, and a distal portion, the phalanges. The proximal part consists of a series of more or less cubical bones which allow a certain amount of gliding on one another and are chiefly concerned in distributing forces transmitted to or from the bones of the forearm or leg. The intermediate part is made up of slightly movable long bones, which assist the carpus or tarsus in distributing forces, and also give greater breadth

* As in the first metacarpal bone (see page 391), so in the first metatarsal, there is sometimes an epiphysis for the head as well as one for the base.

† C. Thurstan Holland, *J. Anat.* 55, 1921.

for the reception of such forces. The separation of the individual bones from one another allows of the attachments of the interosseous muscles and protects the dorsipalmar and dorsiplantar vascular anastomoses. The distal portion is the most movable, and its separate elements enjoy a varied range of movements, the chief of which are flexion and extension.

The functions of the hand and foot are, however, very different, and the general similarity between them is greatly modified to meet these requirements. Thus, the foot forms a firm basis of support for the body in the erect posture, and is therefore more solidly built, and its component parts are less movable on each other than those of the hand. The architecture of the bones of the hand is designed to provide an efficient instrument of prehension, and its component parts are not only capable of

FIG. 479.—The skeleton of the left foot. Medial aspect.

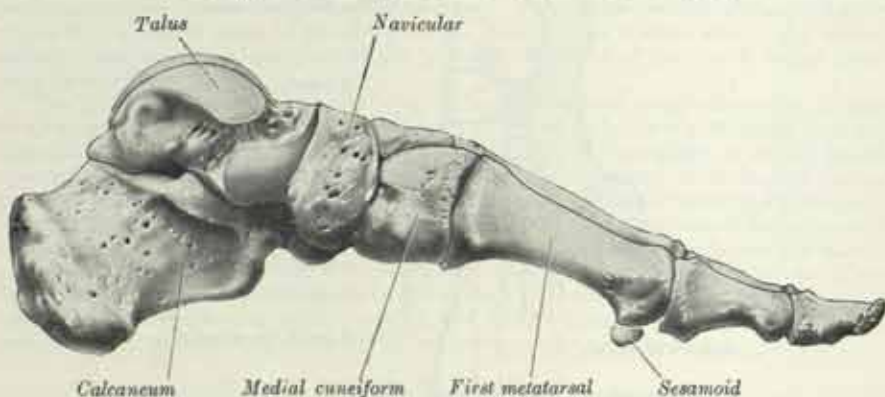
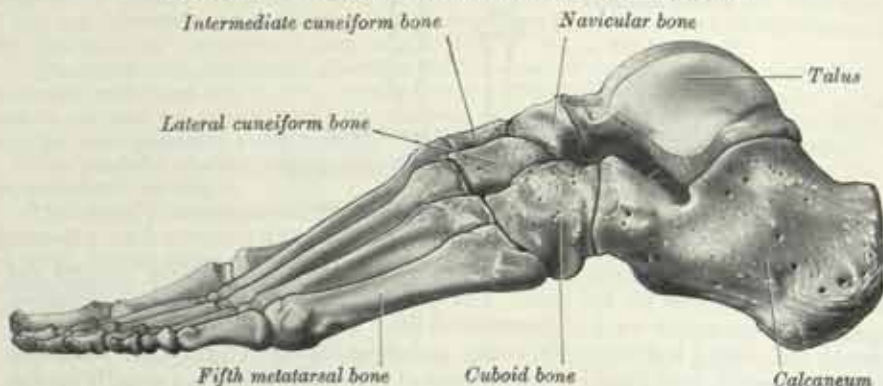


FIG. 480.—The skeleton of the left foot. Lateral aspect.



a greater range of movement but possess a greater degree of independent mobility. In the case of the proximal phalanges the difference is readily noticeable; those of the foot are smaller and their movements more limited than those of the hand. The difference between the metacarpal bone of the thumb and the metatarsal bone of the big toe is very much more marked. The position of the metacarpal bone of the thumb permits of great mobility; as compared with the other metacarpal bones, it is carried forwards and rotated medially round its long axis through an angle of approximately 90° , and it is capable of a considerable range of movement at its articulation with the carpus. The metatarsal bone of the big toe assists in supporting the weight of the body, is constructed with great solidity, lies parallel with the other metatarsals, and has a limited degree of movement. The carpus is small in proportion to the rest of the hand, is placed in line with the forearm, and forms a transverse arch, the concavity of which constitutes a bed for the flexor tendons. The tarsus forms a considerable part of the foot, and is placed at right angles to the leg, a position which is almost peculiar to man, and has relation to his erect posture.

In order to allow them to support the weight of the body efficiently while making provision for the requisite spring and elasticity of the gait, the tarsus and metatarsus are built up into a series of arches (figs. 479, 480), the disposition of which will be considered after the articulations of the foot have been described.

THE SESAMOID BONES *

The **sesamoid bones** are more or less rounded nodules of bone embedded in certain tendons and usually related to articular surfaces. Their functions probably are to modify pressure, to diminish friction, and occasionally to alter the direction of the pull of a muscle. The fact that they are present as cartilaginous nodules in the foetus and in greater numbers than in the adult shows that they are not developed to meet certain physical requirements in the adult. They must be regarded as integral parts of the skeleton phylogenetically inherited.† Physical necessities probably come into play in selecting and in regulating the degree of development of the original cartilaginous nodules.

Sesamoid bones are invested by the fibrous tissue of the tendons, except on the surfaces in contact with the parts over which they glide, where they present smooth articular facets.

In the upper limb the sesamoid bones of the joints are found only on the palmar surface of the hand. Two, of which the medial is the larger, are present at the metacarpophalangeal joint of the thumb, embedded in the tendons of the adductor pollicis and the flexor pollicis brevis; one is frequently present in the corresponding joint of the index finger (35 per cent. of hands), and one in the same joint of the little finger (70 per cent. of hands) (Pl. XII). Sesamoid bones are found occasionally embedded in the palmar ligaments at the metacarpophalangeal joints of the middle and ring fingers, and there may be two at the same joint of the little finger. A sesamoid bone frequently occurs at the interphalangeal joint of the thumb (73 per cent. of hands).

It should be noted that the metacarpophalangeal sesamoids of the thumb appear in males between the twelfth and the fifteenth year and those of the fingers between the thirteenth and the eighteenth years.‡ In the female these bones begin to ossify about three years earlier.

In the lower limb the largest sesamoid bone of the joints is the patella, developed in the tendon of the quadriceps femoris. On the plantar aspect of the foot, two, of which the medial is the larger, are always present at the metatarsophalangeal joint of the big toe, embedded in the tendons of insertion of the flexor hallucis brevis; one sometimes at the metatarsophalangeal joints of the second and fifth toes, one occasionally at the corresponding joints of the third and fourth toes, and one at the interphalangeal joint of the big toe. The medial sesamoid at the metatarsophalangeal joint of the great toe is often double, and the condition may be mistaken for a fracture of the bone.

Sesamoid bones apart from joints are seldom found in the tendons of the upper limb; one is sometimes seen in the tendon of the biceps opposite the radial tuberosity. Sesamoid bones or cartilages are, however, present in several of the tendons of the lower limb—viz. one in the tendon of the peroneus longus where it glides on the cuboid bone; one, appearing late in life, in the tendon of the tibialis anterior, opposite the smooth facet on the distal part of the medial surface of the medial cuneiform bone; one in the tendon of the tibialis posterior, opposite the medial side of the head of the talus; one in the lateral head of the gastrocnemius, behind the lateral condyle of the femur; and one in the tendon of the psoas major where it glides over the ilium. Sesamoid bones are found occasionally in the tendons which wind round the medial and lateral malleoli, and one is sometimes present in the tendon of the gluteus maximus where it passes over the greater trochanter of the femur.

* See A. H. Bizarro, *J. Anat.*, 55, 1921.

† Thilenius, *Morpholog. Arbeiten*, 5, 1896.

‡ J. Joseph, *Personal communication*.

SYNDESMOLOGY

A *JOINT* or *articulation* is formed where two or more bones of the skeleton meet one another. In long bones the ends are the parts which form the joints: in flat bones the joints usually are formed at the edges: and in short and irregular bones the joints may occur at various parts of their surfaces.

The function of the joint is the most important factor in the determination of its character and structure. In some situations, e.g. in the skull, it is important that no movement should be permitted between contiguous bones; in other situations, e.g. in the vertebral column, a slight degree of mobility is advantageous, provided that it can be obtained without any loss of strength; and in still other situations the provision of a more or less wide range of movement is all-important.

In the earlier sections the development of the skeletal system and its component parts has been described, and it has been shown how in the first place the individual bones are laid down as condensations of the mesenchyme. Later, adjoining areas of condensation may become continuous with one another before they undergo the processes of chondrification and ossification. Centres of chondrification and ossification appear and outline the individual bones, which are connected to one another by plates of mesenchyme, often termed *interzonal mesenchyme*. The subsequent history of this mesenchymal plate differs in different types of joint. It may become converted into white fibrous tissue; it may be converted into cartilage; or it may break down centrally and leave a space between the two opposed bones. In the first case the connecting medium between the bones concerned becomes converted into white fibrous tissue, made up of numbers of short, collagenous fibres running between the opposing ends: such joints are almost immovable and are termed *fibrous joints*. In the second case the connecting medium between the bones concerned becomes converted into cartilage; such joints are capable of a limited range of movement, and are termed *cartilaginous joints*. In the third case the central part of the interzonal mesenchyme becomes a loose meshwork which soon gives rise to the interarticular part of a joint cavity, while the interzonal mesenchyme adjoining the opposed ends of the skeletal elements remains condensed and contributes to the formation of the articular surfaces of the bones concerned.* The peripheral part of the joint cavity is formed by an extension of the cavitation into the surrounding vascular mesenchyme which is enclosed by the development of a fibrous cuff, termed the *fibrous capsule* or *fibrous membrane*, around the joint. The vascular mesenchyme forms the wall of the peripheral part of the joint cavity and constitutes a *synovial membrane*. It also gives rise to intra-articular structures such as articular discs and ligaments (*vide infra*). The fibrous capsule and synovial membrane together constitute the *articular capsule*. Intracapsular ligaments and tendons develop *in situ* and do not migrate through the fibrous capsules into the joint. Joints with an articular cavity possess a more or less wide range of movement and are termed *synovial joints*.†

In joints where only a slight degree of movement is required, the desired result is obtained by the provision of a cartilaginous joint when adequate leverage is available, e.g. in the joints between the bodies of the vertebræ. In some situations, however, e.g. in most of the carpometacarpal joints, the necessary leverage cannot be obtained and synovial joints are essential to provide even very limited degrees of movement.

All the joints in the human body fall into one of these three categories, and the salient features of each group must be considered, before the individual joints of the body can be described in detail.

A CLASSIFICATION OF THE JOINTS

Joints are divided into three classes: *fibrous joints*, *cartilaginous joints*, and *synovial joints*.

* R. W. Haines, *J. Anat.*, Lond., 81, 1947.

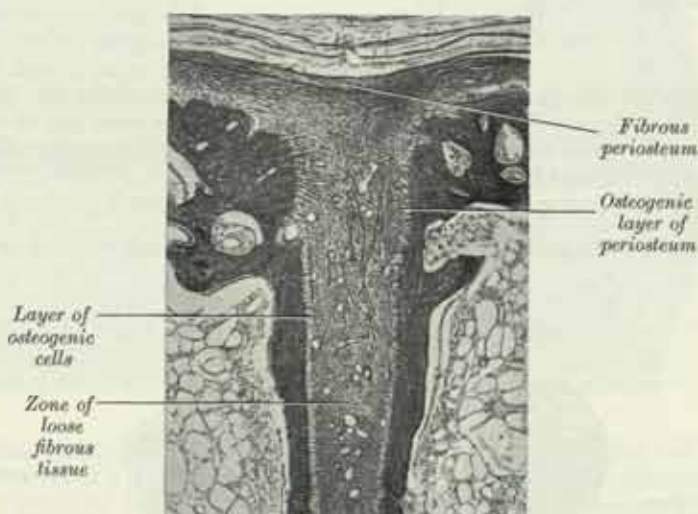
† E. Gardner and D. J. Gray, *Amer. J. Anat.*, 86, 87, 1950; 88, 1951.

1. FIBROUS JOINTS. [JUNCTURAE FIBROSÆ]

Fibrous joints are articulations in which the surfaces of the bones are fastened together by intervening fibrous tissue, and in which there is no appreciable motion, as in the joints between the bones of the cranium. There are three types of fibrous joints: sutures, gomphoses and syndesmoses. Sutures, however, can be subdivided into several different varieties.

A **suture** is an articulation met with only in the skull, where the margins of the bones articulate with one another (fig. 481), but are separated by a thin layer of fibrous tissue, which is named the *sutural ligament*. The margin of each bone is covered by a layer of flattened osteogenic cells and a lamella of fibrous tissue, which are continuous with the corresponding layers of the periosteum over their non-articular surfaces. Between the adjacent fibrous lamellae is a looser zone of fibrous connective tissue containing thin walled blood vessels, which, in the vault of the

FIG. 481.—Section of the internasal suture of a 57-day-old cat. (Kindly lent by Professor J. J. Pritchard.)



skull, communicate with the diploic veins, the dural venous sinuses and the veins of the scalp. The fibrous layers of the internal and external periosteae of adjacent bones are continuous across the suture and form the chief band of union between the bones. In the young, the bones expand by growth at sutures. During this period the layer of osteogenic cells covering the margins is well developed and areas of secondary cartilage are frequently found in the sutural ligaments.*

When the bony margins are provided with saw-like edges the articulation is termed a *serrate suture*, such as the sagittal suture of the skull. When the margins present a series of tooth-like processes which widen towards their free ends, the articulation is named a *denticulate suture*. Where one bone overlaps another, as in the suture between the temporal and parietal bones, it is named a *squamous suture*; where the overlapping edges are ridged or serrated it is named a *limbous suture*; where there is simple apposition of contiguous rough surfaces, as between the palatine processes of the maxillæ, or between the horizontal plates of the palatine bones, it is named a *plane suture*. A *schindylesis* or *wedge-and-groove suture* is a joint where a ridge fits into a grooved surface; it is seen in the articulation between the rostrum of the sphenoid and the upper border of the vomer.

At birth the right and left halves of the mandible are united in the median plane by fibrous tissue, but during the first year this fibrous union becomes converted into bone (p. 309). The zone of union is often referred to as the *symphysis menti*.

A **gomphosis** or *peg-and-socket joint* is articulation by the insertion of a conical

* J. J. Pritchard, J. H. Scott and F. G. Girgis, *J. Anat., Lond.*, 90, 1956.

process into a socket ; it is seen in the articulations of the roots of the teeth with the alveoli of the mandible and maxilla.

A **syndesmosis** is a joint in which the opposed bony surfaces are connected by an interosseous ligament, as in the tibiofibular syndesmosis.

2. CARTILAGINOUS JOINTS. [JUNCTURAE CARTILAGINEÆ]

In these articulations the opposed bony surfaces are connected to each other by cartilage, and a limited amount of movement may be possible.

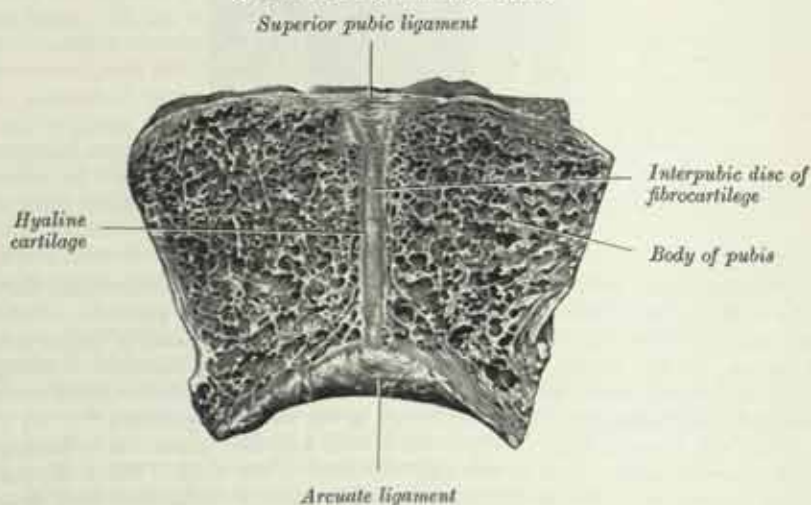
In some cartilaginous joints, which are termed *synchondroses* (primary cartilaginous joints) the cartilage is hyaline in character and temporary in nature. It is ultimately replaced by bone (fig. 482). Such joints are found between the epiphyses and diaphyses of long bones, between the occipital and sphenoid bones at and for some years after birth, and between the petrous parts of the temporal bones and the jugular processes of the occipital bone. No movement is permitted at these joints, for the cartilaginous plate is relatively thin and the necessary leverage cannot be obtained.

In other cartilaginous joints (secondary cartilaginous joints) the opposed bony surfaces are covered with hyaline cartilage, and are connected to each other by a flattened disc of fibrocartilage of a more or less complex structure (fig. 483). The bones are also connected by bands of white fibrous tissue termed ligaments, which, however, do not form a complete capsule round the joint. A limited degree of movement is permitted and it is rendered possible by the compressibility of the cartilaginous disc and the degree of leverage which is available. Such joints are generally

FIG. 482.—A section through the spheno-occipital joint of an infant.



FIG. 483.—An obliquely coronal section through the symphysis pubis to show the structure of a cartilaginous joint.



permanent and are represented by the joints between the vertebral bodies, the joint between the manubrium and the body of the sternum, and the joint between the pubic bones, which is termed the pubic symphysis. All these articulations lie in the median plane of the body.

3. SYNOVIAL JOINTS. [JUNCTURAE SYNOVIALES]

Most of the joints of the body, including all the joints of both limbs, with the exception of the tibiofibular syndesmosis and the pubic symphysis, belong to the synovial group. They have certain definitely characteristic features. (1) The contiguous bony surfaces are covered with articular cartilage and are not attached to one another. (2) There is a joint cavity, which is reduced to a potential space in the normal healthy condition during life. (3) The joint is completely surrounded by an articular capsule, which consists of a fibrous capsule lined with a synovial mem-

brane. (4) The synovial membrane lines the whole of the interior of the joint with the exception of the cartilage-covered ends of the articulating bones. (5) The bones are usually connected by a variable number of ligaments which are additional to the fibrous capsule and usually superficial to it. (6) On account of the nature of the connexions between the bones concerned, movement is always possible in a synovial joint: it may vary from a gliding movement, very limited in range, such as is permitted between the bases of adjoining metacarpal bones, to the wide range of movement of the shoulder joint.

In addition, the joint-cavity may be divided, completely or incompletely, by an *articular disc* or a *meniscus* consisting of fibrocartilage (fig. 484B) in which the fibrous tissue predominates and the cartilage cells are few and far between. Peripherally articular discs and menisci are continuous with the fibrous capsule of the joint

FIG. 484A.—A section through a simple synovial joint. Diagrammatic.

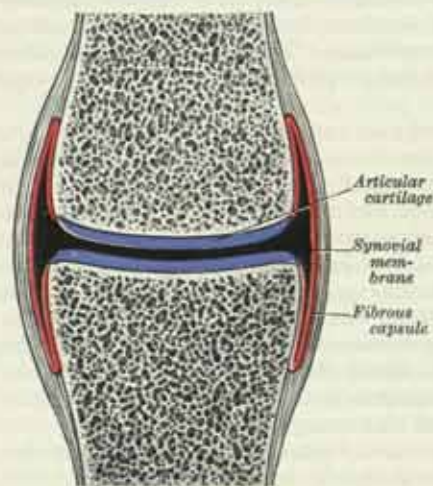
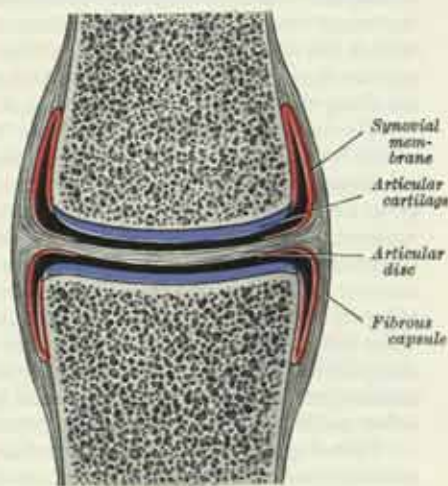


FIG. 484B.—A section through a synovial joint with an articular disc. Diagrammatic.



through the medium of a loosely arranged and vascular fibro-areolar tissue; their free surfaces may be partially covered by flattened cells which are continuous at the periphery with the surface cells of the adjoining synovial membrane; there is, however, little resemblance between the surface cells of the articular discs and the synovial cells (*vide infra*). The articular discs help to maintain perfect lubrication. They occur in joints where gliding is associated with angular movement.* They serve to minimise attrition of the articular surfaces and to increase the range of movement by converting what is in fact a single joint into two (p. 460).

Articular discs or menisci are present in the temporomandibular (p. 458), the sternoclavicular, acromioclavicular, inferior radio-ulnar and knee joints.

The **articular cartilage** which covers the articular surface of a bone is usually hyaline in character, but in the cases of bones which ossify in membrane it is white fibrocartilage. It contains neither nerves nor blood-vessels, and its nutrition is derived from the vascular network in the synovial membrane at its periphery, from the synovia which lubricates the joint and from the blood vessels in the underlying marrow spaces (*vide infra*). Macroscopically its free surface is smooth and has no covering perichondrium; microscopically the surface is finely irregular, and minute shred-like projections indicate the effects of normal wear and tear. The deepest part of the articular cartilage is calcified and is firmly attached to the articular surface of the bone, which is formed by a compact layer termed the *articular lamella*. The blood vessels of the underlying marrow spaces terminate in this region as loops, some of which penetrate the articular lamella and enter the calcified layer of the articular cartilage. A few vessels extend beyond this into the deeper part of the uncalcified cartilage.†

* C. H. Barnett, *J. Anat.*, Lond., **88**, 1954.

† D. E. Holmdahl & Bo. E. Ingelmark, *Acta orthopaed. scand.*, **20**

The **fibrous capsule** consists of parallel and interlacing bundles of white connective tissue fibres. It forms a sort of cuff or brassard, each end of which is attached to a continuous line around the articular end of one of the bones concerned, usually in the immediate neighbourhood of the periphery of the articular surface, but this arrangement is subject to considerable variation. It is perforated by the articular vessels and nerves, and may present one or more apertures through which the synovial membrane protrudes to form a pouch or sac. The fibrous capsule usually shows two or more localised thickenings in which the constituent fibre bundles are generally parallel to one another. These thickenings are the **ligaments of the joint** and they are named according to their position or attachments. In some joints the fibrous capsule is reinforced or replaced by the tendons, or by expansions from the tendons, of neighbouring muscles. Some joints possess **accessory ligaments** which stand clear of the fibrous capsule. Such accessory ligaments may be situated outside the capsule, or they may be intracapsular.

All ligaments are tough and unyielding, but at the same time flexible and pliant, so that they offer no resistance to normal movements. They are designed to prevent the occurrence of excessive or abnormal movements, and every ligament becomes taut at the normal limit of some particular movement. They are elastic only within narrow limits,* and are not designed to withstand prolonged tension, pain always resulting when they are subjected to it.

The **synovial membrane** lines the fibrous capsule and covers those parts of the bones which are within the capsule, but ceases at the margins of the articular cartilages, which it usually overlaps to a slight extent. Speaking broadly, it gives a covering to all intracapsular structures, but this statement requires a certain amount of qualification (*see later*). In many joints the synovial membrane forms fringe-like processes, usually containing small pads of fat, which project into the interior and fill up any irregularities or potential spaces in the joint (fig. 513). The synovial membrane secretes a small quantity of viscid glairy fluid termed *synovia*. This fluid acts as a lubricant and may help to nourish the articular cartilage. Its composition suggests that it is a dialysate of blood plasma with the addition of the mucosubstance *hyaluronic acid* which is distinct from that of cartilage. It contains a few nucleated cells, chiefly monocytes and clasmotocytes.†

Histologically the synovial membrane consists, typically, of a delicate, vascular, cellular connective tissue, covered on its free surface by an incomplete layer of cells, which are irregular in shape and are not accurately opposed to one another like the cells lining the serous cavities.‡ These superficial cells (sometimes termed *synovial cells*) differ from the deeper cells in the membrane by their staining reactions. They are responsible for the secretion of the hyaluronic acid, which is the characteristic constituent of the synovial fluid. In addition, the synovial cells are capable of removing particulate matter§ from the joint cavity and transferring it to cells in the deeper part of the membrane, and so, following hæmorrhage into the joint, they are found to be laden with hæmosiderin. Further they are probably the active agents in the absorption of the cartilaginous debris caused by ordinary wear and tear.

Deep to the synovial cells, the collagenous groundwork of the synovial membrane is traversed by numerous fine fibres, many of them elastic fibres, and contains large numbers of connective tissue cells of different types, including fibroblasts and mast cells. Reticulo-endothelial cells are present.

In different parts of the same joint the synovial membrane varies in thickness and has been classified as (i) fibrous, (ii) fatty and (iii) areolar.|| The so-called fibrous type is thin and is intimately related to the deep surfaces of ligaments and intracapsular tendons such as the long tendon of the biceps brachii and the popliteus muscles. The fatty type includes all projections of fatty tags into joint cavities and is regarded as being less active physiologically than the areolar type, the details of which have been summarised above.||

The synovial sheaths of tendons and the synovial bursæ are closely related in structure and function to the synovial membrane of joints.

* J. W. Smith, *J. Anat., Lond.*, **88**, 1954.

† W. Bauer, M. W. Ropes and H. Waive, *Physiol. Rev.* **30**, 1940.

‡ D. V. Davies, *B.M.J.*, **1**, 1950.

§ W. E. Le Gros Clark, *J. Anat. Lond.*, **63**, 1929.

|| J. A. Key, E. V. Cowdrey's *Special Cytology*, 2nd edition, **2**, Hoeber, New York, 1932.

Classification.—Synovial joints are classified according to the kind of motion permitted in them. There are two varieties in which the movement is uni-axial; that is to say, all movements take place around one axis. In one, the *ginglymus* or *hinge joint*, this axis is, practically speaking, transverse; in the other, the *articulatio trochoidea* or *pivot joint*, it is longitudinal. There are two varieties where the movement is bi-axial; these are the *articulatio condylaris* or *condyloid joint* and the *articulatio sellaris* or *saddle joint*. There is one form where the movement is poly-axial, the *articulatio cotylica* or *ball-and-socket joint*; and finally there is the *articulatio plana* or *plane joint*.

Ginglymus or hinge joint.—In this form the articular surfaces are moulded to each other in such a manner as to permit motion in one plane only. On each side of the articular surfaces the bones are connected together by strong collateral ligaments, which form their chief bond of union. The best examples of hinge joints are the interphalangeal joints, and the humero-ulnar joint.

Articulatio trochoidea or pivot joint.—Where the movement is limited to rotation, the joint is formed by a pivot turning within a ring, or a ring turning on a pivot, the ring being formed partly of bone, partly of ligament. In the proximal radio-ulnar joint, the ring is formed by the radial notch of the ulna and the annular ligament; here, the head of the radius rotates within the ring. In the articulation of the dens of the axis with the atlas, the ring is formed in front by the anterior arch, and behind by the transverse ligament of the atlas; here, the ring rotates round the dens.

Condyloid articulation.—In this form of joint, an ovoid, convex, articular surface, or condyle, is received into an elliptical concavity in such a manner as to permit of flexion, extension, adduction, abduction, circumduction and, as an accessory movement, axial rotation. The radiocarpal joint is an example of this form of articulation. (See also p. 500, *Accessory movements*.)

Saddle articulation.—In this variety the opposing surfaces are reciprocally concavoconvex, and the movements are the same as in the preceding form. The best example of the saddle articulation is the carpometacarpal joint of the thumb.

Articulatio cotylica or ball-and-socket joint.—In this type of joint the distal bone is capable of motion around an indefinite number of axes, which have one common centre. It is formed by the reception of a globular head into a cup-like cavity, hence the name 'ball-and-socket.' Examples of this form of articulation are found in the hip and shoulder joints.

A **plane joint** is one which admits of gliding movement only; it is formed by the apposition of nearly plane surfaces, the amount of motion in such joints being limited by the ligaments or osseous processes surrounding the articulations. It is seen in the joints between the articular processes of the vertebræ, and in most of the carpal and tarsal joints.

THE MOVEMENTS AND MECHANISMS OF JOINTS

The movements permitted in joints are of four kinds: gliding and angular movements, circumduction, and rotation. Frequently these are more or less combined, so as to produce an infinite variety, and it is seldom that only one kind of motion is found in any particular joint. Where movement is limited, the reciprocal articular surfaces are approximately equal in size, but where movement is free, the more movable bone usually possesses the larger surface.

Gliding movement is the simplest kind of motion that can take place in a joint, one surface gliding over another without any angular or rotatory movement. It occurs in many synovial joints; but in some, as in most of the articulations of the carpus and tarsus, it is the only motion permitted.

Angular movement implies diminution, or increase, of the angle between adjoining bones. Two types of angular movement are so common, especially in the joints of the limbs, that they must be defined. They occur around axes which are set at right angles to each other and are: (1) *flexion*, or bending, and its opposite, *extension*, or straightening, and (2) *abduction* and its opposite, *adduction*.

Flexion occurs around an axis which is transverse or obliquely transverse, and usually results in the approximation of two morphologically ventral surfaces. This definition is not entirely satisfactory, for its first part does not hold good for the joints of the thumb; and its second part, in the case of the shoulder, hip and

talocrural joints. The thumb lies in a plane set at right angles to the plane of the fingers. As a result its dorsal surface is directed laterally, and flexion and extension at each of its joints occur around an anteroposterior axis. At the shoulder joint flexion carries the arm forwards and medially, and its morphologically ventral surface is brought no nearer to the ventral aspect of the trunk. At the hip joint, owing to the changes which occur in the early stages of development (p. 120), flexion approximates the morphologically dorsal surface of the thigh to the ventral surface of the trunk. The condition of the talocrural joint is complicated by the fact that the foot is set at a right angle to the leg. Bending movement of the talocrural joint implies a diminution of the angle and is frequently termed flexion. On the other hand it results in the approximation of two morphologically dorsal surfaces and might, with an equal amount of justification, be termed extension. It will avoid confusion and misunderstanding if the self-explanatory terms *dorsi-flexion* and *plantar-flexion* are used in connexion with the movements at the talocrural joint.*

Abduction and adduction occur around a more or less anteroposterior axis, except in the case of the carpometacarpal joint of the thumb, where, for reasons already stated, these movements occur around a transverse axis. The terms imply movements from and to the median plane of the body, except in the cases of the digits, where the plane of reference is the median plane of the middle digit (in the hand) or the second digit (in the foot).

Circumduction takes place between the head of a bone and its articular cavity when the bone is made to circumscribe a conical space; the base of the cone is described by the distal end of the bone, the apex is in the articular cavity; this kind of motion is best seen in the shoulder and hip joints.

Rotation is a form of movement in which a bone moves round a longitudinal axis; the axis of rotation may lie in a separate bone, as in the case of the pivot formed by the dens of the axis, around which the atlas turns; or a bone may rotate around its own longitudinal axis, as in the rotation of the humerus at the shoulder joint; or the axis of rotation may be not quite parallel to the long axis of the bone, as in the movement of the radius on the ulna during pronation and supination of the hand, where it is represented by a line connecting the centre of the head of the radius with the centre of the head of the ulna.

Although it is customary and often convenient to describe joint surfaces as cylindrical, spherical or plane, it is important to realise that these are approximations only and that the configuration of the articular surfaces never conform exactly to those of simple geometrical figures. Thus the articular surfaces of most hinge joints are not segments of regular cylinders and their profiles are not arcs of circles but spirals. Similarly in ball-and-socket joints the surfaces are never truly spherical. Likewise the articular surfaces of a joint are, as a rule, congruous only in one, commonly the weight-bearing, phase.† This is full extension in the hip and knee joints. In all other phases the entering or male surface generally has a smaller radius of curvature than the female surface, resulting in a wedge-shaped interval, filled by a convergent film of synovial fluid, between the articular surfaces. This interval is necessary for the efficient lubrication of the joint. Articular discs and menisci are believed to assist lubrication by preventing the full apposition of the articular surfaces and thus maintaining this wedge-shaped interval. On the other hand fat pads and synovial folds help to reduce this interval to within functional limits when the articular surfaces of the bones diverge widely.‡

Furthermore, it must be noted that so-called hinge joints, such as the elbow and talocrural, are in fact saddle joints and that consequently some degree of axial rotation accompanies flexion and extension.§ It is probable that a similar axial

* Flexion has also been defined as the position assumed by the joints of the foetus 'in utero.' Such a definition would imply that 'dorsi-flexion' of the talocrural joint is really 'flexion.' This view is supported by the physiological observation that in reflexes involving all the joints of the lower limb flexion at the hip and knee joints is always associated with 'dorsi-flexion' of the talocrural joint, and extension of the hip and knee joints with 'plantar-flexion' of the talocrural joint. The definitions based on morphological and physiological criteria are contradictory to each other and this emphasises the desirability for the use of the makeshift terms suggested in the text.

† T. Walmsley, *J. Bone Jt. Surg.*, 10, 1928.

‡ M. A. MacConaill, *Irish J. med. Sci.*, 1946.

§ C. H. Barnett and J. R. Napier, *J. Anat. Lond.*, 86, 1952.

rotation is associated with the movement in other types of joints and that most movements are in fact circumductions though the axial rotation is not always evident. This accompanying axial rotation has been termed *conjunct rotation*.^{*} It occurs between all the segments of the lower limb in normal walking movements. The purpose of this rotation is not clear but it is of interest in relation to torsional strains in bone and to the production of spiral fractures.

Accessory movements.—The movements which can be performed actively at any joint do not necessarily include all the movements which the structure of the joint would permit. Certain movements which cannot be performed voluntarily can nevertheless be produced when resistance is encountered to active movements (accessory movements, first type), e.g. it is only when some solid object, such as a cricket ball, is grasped in the hand, that the fingers can be rotated at the metacarpophalangeal joints. Other movements can be produced only passively (accessory movements, second type) and their widest range is obtained when the muscles acting on the joint are fully relaxed, e.g. when the arm is partially abducted at the shoulder joint, the humerus can be drawn away from the glenoid cavity. Such movements are commonly termed 'passive movements', but as all movements, whether active or not, can be performed passively when the muscles concerned are relaxed, the term *accessory movements* will be used to designate all movements which cannot be performed actively in the absence of resistance.

The possibility of accessory movements implies a certain amount of play between the articular surfaces of a joint, and this prevents undue strain or pressure on those surfaces when the joint is subjected to violent stresses. A considerable amount of play is permitted in the shoulder joint, but none is permitted in the hip joint. As a result damage of the articular surfaces is very much commoner in the latter, and the disease of osteoarthritis, which has its origin in trauma of an articular surface, is of much more frequent occurrence in the hip than in the shoulder joint.

Limitation of movements is effected by a number of different factors, of which the *tension of ligaments* is very important, as can be seen when attempts are made to produce hyperextension of the dissected knee or hip joints. In life, however, the *tension of the muscles which are antagonistic to the movement* is equally important, if not more so, for it is open to doubt whether under normal conditions the tension of the antagonist muscles ever permits a ligament to be put fully on the stretch. The part played by muscles in limiting movement is well seen in flexion of the hip joint. When this movement is performed with the knee extended, it is much more limited in range than when it is performed with the knee flexed. In the latter case flexion of the knee relaxes the ham-string muscles, and this permits the thigh to be flexed until it comes into contact with the anterior abdominal wall. The movement is then limited by the *approximation of the soft parts concerned*—a third factor which is present in connexion with some other movements, e.g. flexion of the elbow and knee.

In synovial joints, where the bones concerned are connected by ligaments and muscles only, the articular surfaces are in constant apposition in all positions of the joint. The maintenance of this apposition is assisted by atmospheric pressure and the force of cohesion, but these factors are merely subsidiary to the influence exerted by the muscles. The balance between the normal tonus of the different muscle groups which act on the joint is responsible for maintaining the articular surfaces in constant apposition. In this connexion it cannot be emphasised too strongly that the stability of any joint depends on the tonus of the muscles which act on it. The erect attitude is maintained by the balance between opposing muscle groups, and in the maintenance of this and other normal postures the ligaments play no part.

Blood supply and lymph.—Joints receive their blood-supply from periarticular arterial plexuses, from which numerous offsets pierce the capsular ligament to form a vascular plexus in the deeper parts of the synovial membrane (fig. 540). The blood vessels of the synovial membrane terminate around the articular margins in a fringe of looped anastomoses termed the *circulus articuli vasculosus*.

The lymphatics form a plexus in the synovial membrane and drain along the blood vessels to the regional deep lymphatic glands.

Nerve supply.—Movable joints are innervated by the nerves of supply to the muscles which act on them, and it is probable that this arrangement establishes local reflex arcs which tend to ensure stability. The nerves consist of medullated and non-medullated fibres. Many of the latter are vasomotor in function whilst

* M. A. MacConaill, *J. Bone Jt. Surg.*, 32B, 1950.

the larger nerve fibres terminate in pressure and tension corpuscles (described by Ruffini) in the fibrous capsule. Free nerve endings are numerous at the attachments of the fibrous capsule and ligaments.* The part of the articular capsule which is rendered taut on the contraction of a given muscle or group of muscles is innervated by the nerve or nerves supplying their antagonists.† For example, the inferior part of the articular capsule of the hip joint, which is put on the stretch in abduction, is supplied by the obturator nerve. Tension of this part of the capsule produces a reflex contraction of the adductor muscles which, usually, is successful in preventing over-stretching or tearing of the ligament.

In the synovial membrane no special end-organs and few free nerve endings are present, apart from those which are associated with the blood vessels. The membrane is relatively insensitive to pain.‡

THE TEMPOROMANDIBULAR JOINT

The bony parts entering into the formation of the mandibular joint are : above, the articular tubercle and the anterior portion of the mandibular fossa of the temporal bone ; below, the head of the mandible. The *articular surfaces* are covered with a variety of white fibrocartilage in which the fibres predominate and cartilage cells are few in number. An articular disc divides the joint into upper and lower cavities.

The **fibrous capsule** is attached, above, to the articular tubercle in front ; to the lips of the tympanosquamosal fissure behind ; and between these two attachments, to the circumference of the mandibular fossa ; below, to the neck of the mandible. Above the articular disc, the capsule forms a loose envelope, but below the disc it is taut. The *synovial membrane* lines the fibrous capsule except where the latter becomes continuous with the peripheral border of the articular disc. Below it is reflected upwards on the neck of the mandible, and the lateral pterygoid tendon to the margin of the articular cartilage of the head.

The **lateral (temporomandibular) ligament** (fig. 485) is placed on the lateral side of the joint and is intimately related to the fibrous capsule. It is attached, above, to the tubercle on the root of the zygoma ; below, to the lateral surface and posterior border of the neck of the mandible. Its fibres are directed obliquely downwards and backwards and are covered superficially by the parotid gland.

The **sphenomandibular ligament** (fig. 486) is placed on the medial side of the joint and is separated from the articular capsule by a considerable interval. It is a flat, thin band which is attached above to the spine of the sphenoid bone, and, becoming broader as it descends, is fixed to the lingula of the mandibular foramen. Laterally it is related, above, to the lateral pterygoid muscle and the auriculotemporal nerve ; lower down, it is separated from the neck of the mandible by the maxillary vessels ; still lower, the inferior alveolar vessels and nerve and a lobule of the parotid gland lie between it and the ramus of the mandible and it is pierced by the vessels and nerve to the mylohyoid muscle. Medially it is related, below, to the medial pterygoid muscle ; above, it is separated from the pharynx by fat and some pharyngeal veins and, near its upper end, it is crossed by the chorda tympani. Some of its fibres can be traced through the medial end of the petrotympanic fissure to the primary attachment, viz. the anterior process of the malleus, which represents a portion of the cephalic extremity of Meckel's cartilage. These fibres constitute a part of the anterior ligament of the malleus (p. 118).

The **articular disc** (fig. 487) is an oval plate, consisting mainly of fibrous tissue, which divides the joint into two cavities. Its upper surface is concavoconvex from before backwards, to accommodate itself to the form of the articular fossa and the articular tubercle. Its under surface, in contact with the head of the mandible, is concave. Its circumference is connected to the fibrous capsule and, in front, to the tendon of the lateral pterygoid muscle (p. 562). Medially and laterally short but

* E. D. Gardner, *Physiol. Rev.*, 30, 1950.

† E. D. Gardner, *Anat. Rec.*, 101, 102, 1948. This statement may require some qualification, for, although it holds good for the hip and elbow joints, it does not appear to hold good for the shoulder joint, in which the axillary nerve is described as supplying the antero-inferior part of the articular capsule.

‡ J. H. Kellgren and E. P. Samuel, *J. Bone Jt. Surg.*, 32B, 1950.

FIG. 485.—The left temporomandibular joint. Lateral aspect.

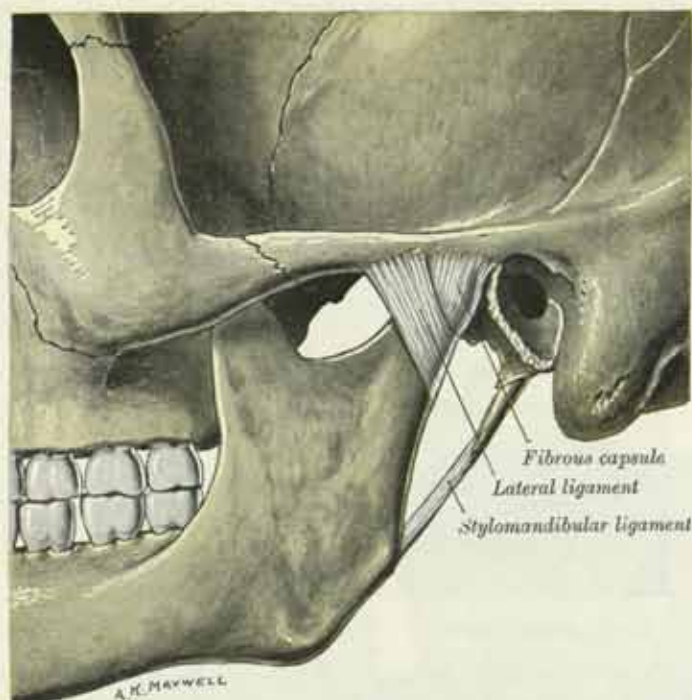
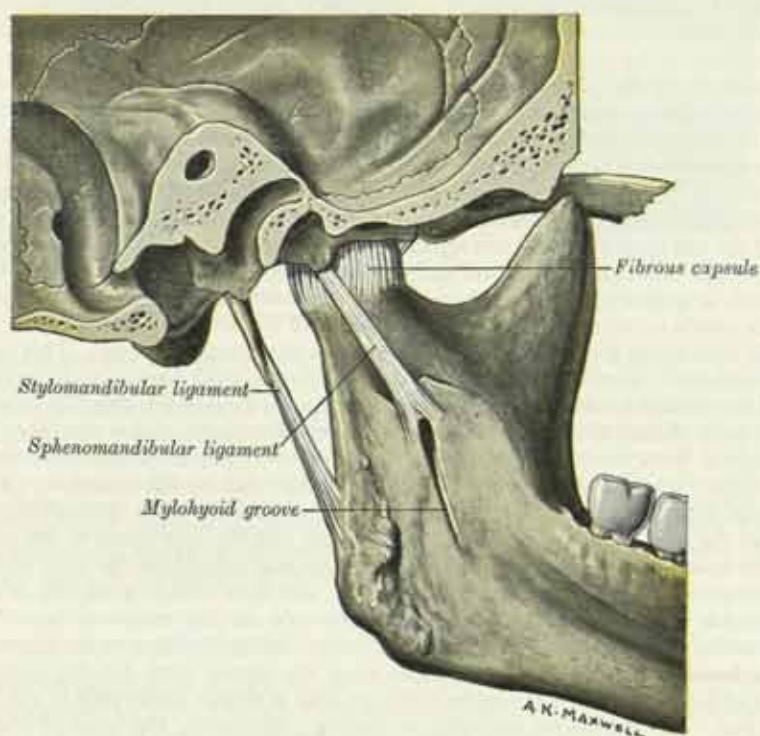
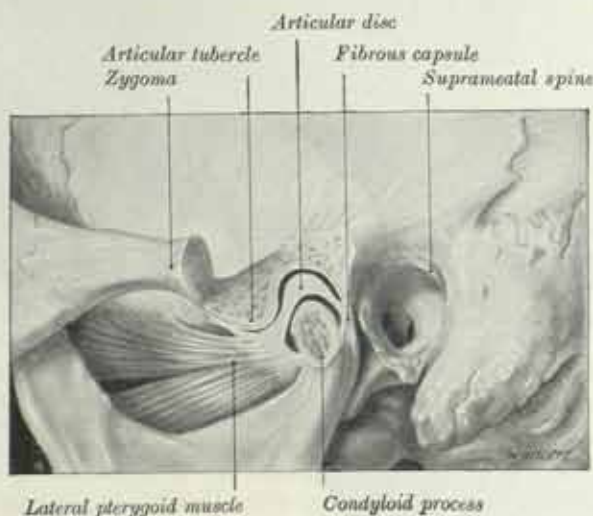


FIG. 486.—The left temporomandibular joint. Medial aspect.



strong fibrous bands pass from the margin of the disc to the medial and lateral poles respectively of the head of the mandible. These ensure that the disc and the head will move together during protraction and retraction of the mandible. Posteriorly the disc contains a well marked venous plexus and divides into upper and lower lamellæ. The upper lamella consists of fibroelastic tissue and is attached to the

FIG. 487.—A sagittal section through the left temporomandibular joint.



posterior margin of the mandibular fossa. The lower lamella consists of white fibrous tissue and is attached to the back of the condyle of the mandible. It varies in thickness in its different parts and is thickest a little behind its centre, where it occupies the deepest part of the mandibular fossa.

The **stylomandibular ligament** (fig. 485) is a specialised band of the deep cervical fascia (p. 565), which stretches from the apical part of the styloid process to the angle and posterior border of the ramus of the mandible. Although classed among the ligaments of the joint, it can only be considered as accessory to it.

The *nerves* of the joint are derived from the auriculotemporal and masseteric branches of the mandibular nerve; the *arteries*, from the superficial temporal branch of the external carotid artery, and from the maxillary artery.

Movements.—The mandible may be depressed or elevated, and protruded or retracted; a considerable amount of side-to-side movement is also permitted.

It should be noted that in the *position of rest* the teeth of the mandible and maxillæ are not in contact but are separated by a slight interval. On closure of the jaws the teeth come into apposition and this constitutes the *occlusal position*. When the mouth is *opened* the head of the mandible rotates around a bicondylar axis and glides forwards in contact with the lower surface of the articular disc. At the same time the disc slides forwards and downwards on the temporal bone. This movement is produced by the contraction of the lateral pterygoid muscle and carries the head of the mandible with its articular disc which caps it on to the articular tubercle. The forward sliding of the disc ceases when the fibroelastic tissue attaching it to the temporal bone posteriorly has been stretched to its limit. Thereafter, there is some further rotation and gliding forwards of the head of the mandible until it articulates with the most anterior part of the disc and the mouth is opened fully. In *closure* of the mouth the movements are reversed. In the first phase of this movement the head of the mandible glides backwards and rotates on the disc which is held forwards by the lateral pterygoid muscle; this then relaxes gradually to allow the articular disc to glide backwards and upwards on the temporal bone.* In *protrusion* the teeth are retained throughout in the occlusal position so far as possible and the lower teeth are drawn forwards over the upper teeth by the pterygoid muscles of both sides. In *retraction* the mandible is drawn backwards to the position of rest. In the *lateral (grinding or chewing) movements*, the head of one side with its disc glides forwards, rotating on its disc around a vertical axis which passes

* L. A. Rees, *Brit. Dent. J.*, 96, 1954.

immediately behind the head of the opposite side. It then glides backwards rotating in the opposite direction as the head of the opposite side comes forwards in its turn. These alternating movements swing the mandible from side to side.*

Muscles producing the movements :

Depression.—Digastric, Mylohyoid, Geniohyoid and Lateral Pterygoid (of both sides).

Elevation.—Masseter, Temporal and Medial Pterygoid (of both sides).

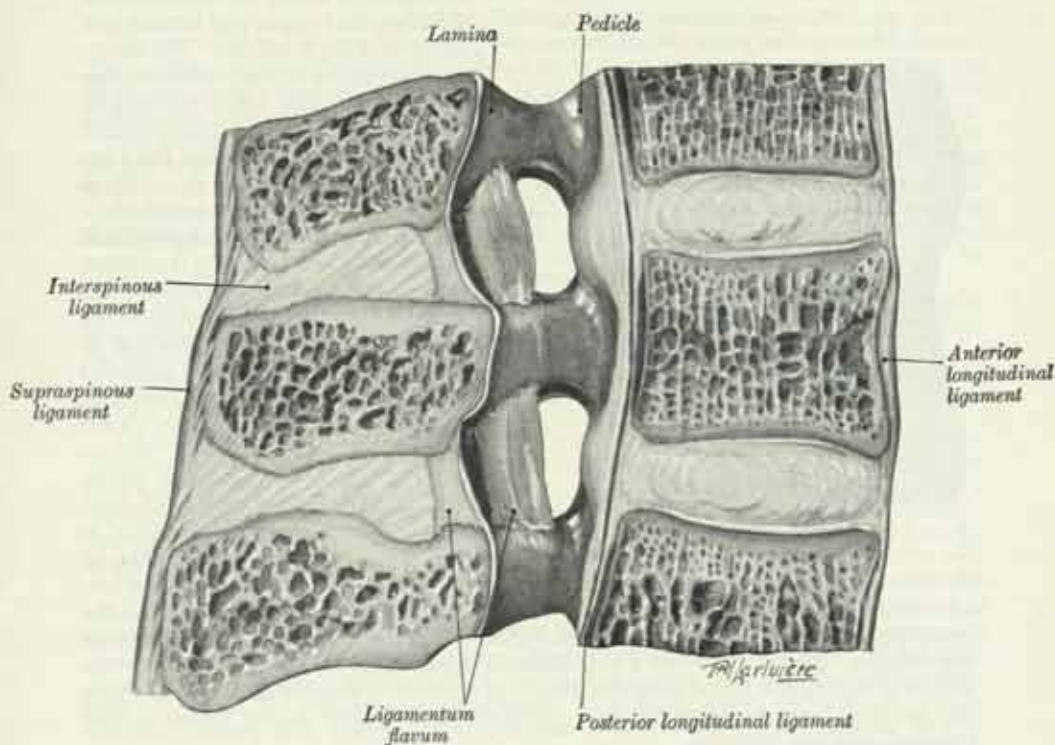
Protrusion.—Medial and Lateral Pterygoid (of both sides).

Retraction.—Temporal (posterior fibres—both sides).

Lateral movements.—Medial and Lateral Pterygoid (of both sides, acting alternately).

Applied Anatomy.—The mandible can be dislocated in one direction only—viz. forwards. When the mouth is open, the head of the mandible is situated on the articular

FIG. 488.—A median sagittal section through a portion of the lumbar region of the vertebral column.



eminence, and any sudden violence, or even a sudden muscular spasm, as during a convulsive yawn, may displace it forwards into the infratemporal fossa. The displacement may be unilateral or bilateral. Reduction is accomplished by depressing the jaw with the thumbs placed on the last molar teeth, and at the same time elevating the chin. The downward pressure overcomes the spasm of the masseter, temporal, and pterygoid muscles, and elevation of the chin throws the head of the mandible backwards; the above-mentioned muscles then draw the head back into its normal position.

The external auditory meatus and the tympanic cavity lie immediately behind the joint; any force, therefore, applied to the mandible is liable to be attended with damage to these parts, or inflammation in the joint may extend to them.

THE JOINTS OF THE VERTEBRAL COLUMN (Plates I and II)

The vertebrae from the second cervical to the first sacral inclusive are articulated to one another by: (1) a series of cartilaginous joints between the vertebral bodies; and (2) a series of synovial joints between the vertebral arches.

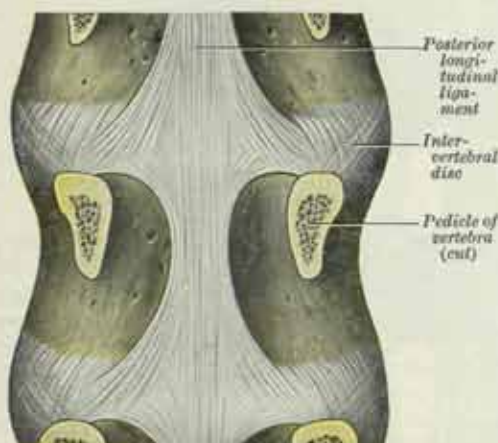
* For further details see *The Temporo-Mandibular Joint*, ed. by B. G. Sarnat, Publ. Charles C. Thomas, Springfield, Illinois, U.S.A., 1951.

1. THE JOINTS OF THE VERTEBRAL BODIES

The vertebral bodies are united by anterior and posterior longitudinal ligaments, and by intervertebral discs of fibrocartilage.

The **anterior longitudinal ligament** (fig. 488) is a strong band of fibres which extends along the anterior surfaces of the bodies of the vertebrae. It is broader below than above, thicker and narrower in the thoracic region than in the cervical and lumbar regions, and somewhat thicker and narrower opposite the bodies of the vertebrae than opposite the intervertebral discs. It is attached, above, to the basilar part of the occipital bone, from which it extends to the anterior tubercle of the atlas, then to the front of the body of the axis and is continued down as far as the upper part of the front of the sacrum. It consists of longitudinal fibres, which are firmly fixed to the intervertebral discs and to the margins of the vertebral bodies, but are loosely attached to the middle parts of the bodies. In the latter situation the ligament is thick and fills up the concavities on the anterior surfaces, and makes the front of the vertebral column more even (fig. 488). It is composed of several layers

FIG. 489.—The posterior longitudinal ligament of the vertebrae, in the lumbar region.



of fibres, of which the most superficial are the longest and extend over three or four vertebrae. The intermediate fibres extend between two or three vertebrae, while the deepest reach from one vertebra to the next. At the sides of the bodies the ligament consists of a few short fibres which connect adjacent vertebrae.

The **posterior longitudinal ligament** (figs. 488, 489) is situated within the vertebral canal on the posterior surfaces of the bodies of the vertebrae. Above, it is attached to the body of the axis, and is thence continued downwards to the sacrum; its upper end is continuous with the *membrana tectoria* (p. 471). It consists of smooth, glistening fibres, which are attached to the intervertebral discs and to the margins of

the vertebral bodies, but are separated from the middle parts of the bodies by the emerging basivertebral veins, and by veins which drain these into the anterior internal vertebral plexuses. In the cervical and upper thoracic regions the ligament is broad and of nearly uniform width, but in the lower thoracic and lumbar regions (fig. 489) it presents a denticulated appearance, being narrow over the vertebral bodies and broad over the discs. It consists of superficial layers bridging the interval between three or four vertebrae, and deeper layers which extend between adjacent vertebrae.

The **intervertebral discs** (figs. 488, 489) are interposed between the adjacent surfaces of the bodies of the vertebrae, from the axis to the sacrum, and form the chief bonds of connexion between the vertebrae. Their shape corresponds with that of the bodies between which they are placed. Their thickness varies in different regions of the column, and in different parts of the same disc; they are thicker in front than behind in the cervical and lumbar regions, and thus contribute to the anterior convexities of these parts of the column; while they are of nearly uniform thickness in the thoracic region, the anterior concavity of this part of the column being almost entirely due to the shape of the vertebral bodies. The discs are thin in the cervical and upper thoracic regions but gradually increase in thickness from thence downwards. They are adherent to thin layers of hyaline cartilage which cover the upper and under surfaces of the bodies of the vertebrae. The discs are closely connected to the anterior and posterior longitudinal ligaments; in the thoracic region they are joined laterally, by means of the intra-articular ligaments, to the heads of those ribs which articulate with two vertebrae. The intervertebral discs constitute about one-fourth of the length of the vertebral column, exclusive of the first two vertebrae; but this amount is not equally distributed, the cervical and

lumbar portions having, in proportion to their length, a much greater amount than the thoracic region, with the result that these parts possess greater pliancy and freedom of movement.

Structure of the intervertebral discs.—In general plan the discs consist of a thin outer zone of collagenous fibres, which form a series of concentric collar-like rings, convex from above downwards. These rings are intimately connected to one another and to a much thicker underlying layer of white fibrocartilage, the collagen fibres of which show a similar concentric arrangement. Together these two layers form the *anulus fibrosus*. In, or a little posterior to, the centre of the disc there is a mass of tissue, termed the *nucleus pulposus*, the structure of which varies at different age periods.*

In the newly born the outer zone of the *anulus fibrosus* forms a relatively thin layer of densely packed collagenous fibres which run with varying degrees of obliquity from the cartilaginous lower surface of the vertebral body above to the cartilaginous upper surface of the one below. The fibre bundles interlace, 'criss-crossing' one another and sometimes joining. In the inner zone of the *anulus*, the individual laminae of the fibrocartilage are separated from one another by cartilage cells and tissue spaces. The *nucleus pulposus* is relatively large and consists of a homogeneous mucoid ground-substance, in which cells of notochordal origin form a wide-meshed and frequently interrupted reticulum, while a few cartilage cells are present in the periphery.

In the child the *anulus fibrosus* thickens and its fibrocartilage becomes denser. The *nucleus pulposus*, which continues relatively large, contains numerous collagenous fibres and small groups of cartilage cells in its mucoid ground-substance from which notochordal cells rapidly disappear and can rarely be identified after the age of 10 years.

By the twenty-first year the *anulus fibrosus* has increased in thickness, especially on the anterior aspect of the disc where it adapts itself to the growth of the vertebral bodies. As a result the *nucleus pulposus* is slightly nearer to the posterior aspect of the vertebral body† Its ground-substance is less translucent, more gelatinous and of firmer consistency. Further, it now contains a quantity of loosely arranged fibrocartilage, which blends circumferentially with the surrounding fibrocartilage of the *anulus fibrosus*.

In the third and following decades the collagenous fibres of the disc grow coarser and become hyalinized, while the *nucleus pulposus* appears to lose fluid and to become desiccated.

After the fifth decade it becomes more and more difficult to differentiate the now fibrocartilaginous *nucleus pulposus* from the rest of the disc.

Applied Anatomy.—In the adult the intervertebral discs are so strong that when violence is applied to the vertebral column the bones always give way first, provided that the discs are healthy. It is impossible to damage a healthy disc except through a fracture of a vertebral body passing through the upper or lower surface of the bone—except in the cervical region, where, as the result of forcible flexion, rupture of the disc may occur without fracture of a vertebral body.

After the second decade, however, degenerative changes are liable to occur in the discs and these may result in necrosis and sequestration of the *nucleus pulposus* and in softening and weakening of the *anulus fibrosus*. Under these circumstances a comparatively minor strain may cause either an internal derangement of the joint tissues with eccentric displacement of the *nucleus pulposus* or an external derangement in which the *nucleus pulposus* bulges or actually bursts through the *anulus fibrosus*, usually in a posterolateral direction. In the former the unequal tension within the joint is responsible for muscle spasm and for the sudden violent pain of an acute attack of lumbago; in the latter the projecting *nucleus* is likely to cause irritation of the adjacent nerve root with resulting referred pain, such as sciatica. Derangements of this kind occur most commonly in the lower lumbar region, especially at the lumbosacral joint, and not infrequently in the cervical region at the levels of C. 5-7, but they may occur at any level.

2. THE JOINTS OF THE VERTEBRAL ARCHES

The joints between the articular processes of the vertebrae belong to the plane variety and are enveloped by articular capsules; the laminae, spines and transverse processes are connected by the following ligaments:

Ligamenta flava.	Supraspinous.	Ligamentum nuchae.
Intertransverse.	Interspinous.	

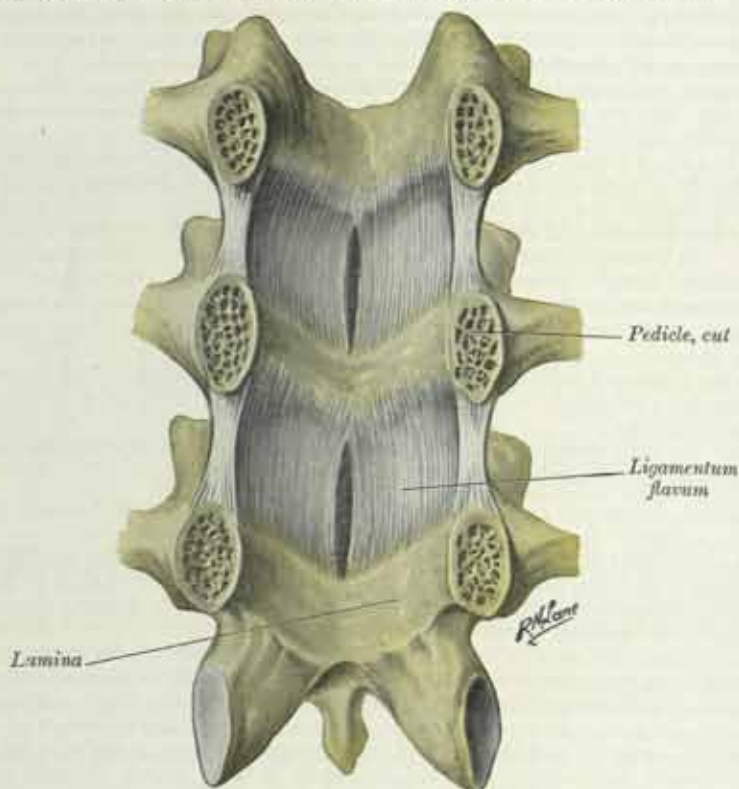
The **articular capsules** are thin and loose, and are attached just beyond the margins of the articular facets of adjacent articular processes; they are longer and looser in the cervical than in the thoracic and lumbar regions.

* A. Peacock, *J. Anat. Lond.*, 86, 1952.

† F. Knutsson, *Acta radiol.*, 30, 1948.

The **ligamenta flava** (figs. 488, 490) connect the laminae of adjacent vertebrae, and are best seen from the interior of the vertebral canal. Their attachments extend from the articular capsules to the regions where the laminae fuse to form the spine; here their posterior margins come into contact and are to a certain extent united, small intervals being left for the passage of vessels. The ligamenta flava consist of yellow elastic tissue, the fibres of which, almost perpendicular in direction, are attached to the lower part of the anterior surface of the lamina above, and to the posterior surface and upper margin of the lamina below. The ligaments are thin, but broad and long in the cervical region; they are thicker in the thoracic region, and thickest in the lumbar region. They prevent excessive flexion and, by virtue of their elasticity, they help to control the movement, graduating it so that its limit is not reached abruptly. In this way they serve to guard against injury of the discs.

FIG. 490.—The ligamenta flava of the lumbar region, viewed from in front.



They also assist in restoring the vertebral column to the erect attitude, after it has been flexed.

The **supraspinous ligament** (fig. 488) is a strong fibrous cord which connects together the apices of the spines from the seventh cervical vertebra to the sacrum; fibrocartilage is developed in the ligament at its points of attachment to the tips of the spines. It is thicker and broader in the lumbar region than in the thoracic, and intimately blended in both situations with the neighbouring fascia. The most superficial fibres of this ligament extend over three or four vertebrae; those more deeply seated pass between two or three vertebrae; while the deepest connect the spines of neighbouring vertebrae. In front it is continuous with the interspinous ligaments. Between the spine of the seventh cervical vertebra and the external occipital protuberance its place is taken by the ligamentum nuchae.

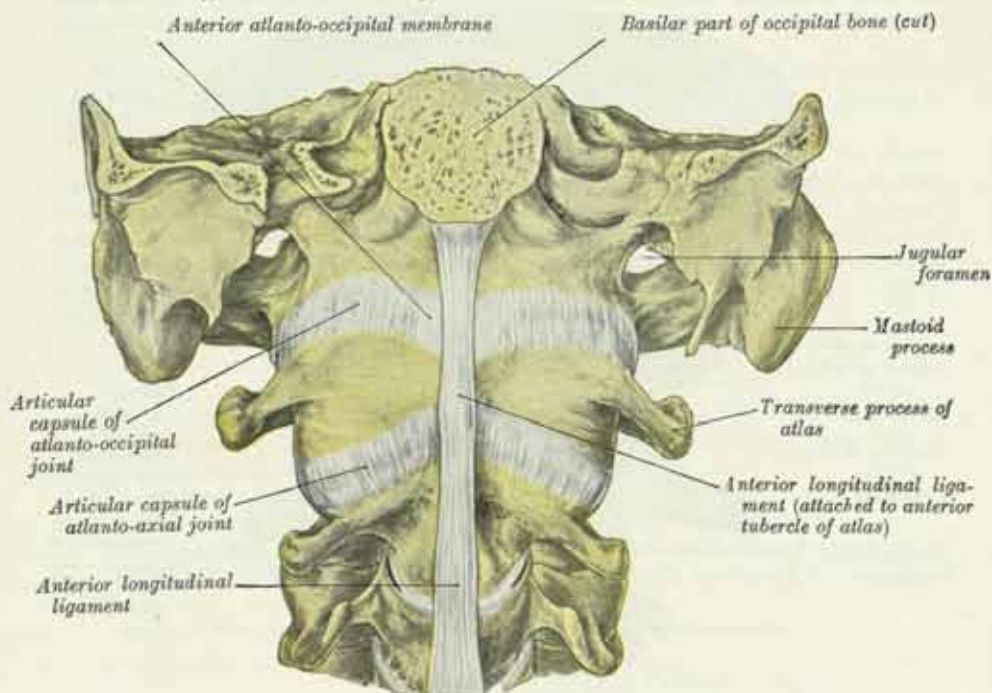
The **ligamentum nuchae** is a fibroelastic membrane, which, in the neck, is homologous with the supraspinous and interspinous ligaments of the thoracic and lumbar vertebrae. Its superficial part extends from the external protuberance and external occipital crest to the spine of the seventh cervical vertebra. From this a fibrous lamina is given off, which is attached to the median part of the squamous

occipital bone below the external occipital protuberance, to the posterior tubercle of the atlas and to the spines of the cervical vertebrae, forming a septum between the muscles of the two sides of the neck. In man it is the representative of an important elastic ligament which, in quadrupedal mammals, controls the movement of flexion of the head, functioning in the same way as the ligamenta flava in man.

The **interspinous ligaments** (fig. 488), thin and membranous, connect adjoining spines, and their attachments extend from the root to the apex of each process. They meet the ligamenta flava in front and the supraspinous ligament behind. They are narrow and elongated in the thoracic region; broader, thicker, and quadrilateral in form in the lumbar region; and only slightly developed in the neck.

The **intertransverse ligaments** are interposed between the transverse processes. In the cervical region they consist of a few, irregular, scattered fibres; in the thoracic region they are rounded cords intimately connected with the deep muscles of the back; in the lumbar region they are thin and membranous.

FIG. 491.—The atlanto-occipital and atlanto-axial joints. Anterior aspect.



On each side a small, occasional, cleft has been opened between the lateral part of the upper surface of the body of the third cervical vertebra and the bevelled, inferior surface of the body of the axis. (See also p. 231.)

Movements of the vertebral column.—The range of movement possible between any two adjoining vertebrae is very restricted, and this limitation is to be attributed to the presence of the intervertebral disc connecting the vertebral bodies. The greater thickness of the discs in the cervical and lumbar regions as compared with the thoracic region is associated with the greater individual ranges of movement occurring in those regions. But, although the range of movement between any two adjoining vertebrae is small, the summation of these movements gives a relatively wide range of movement to the vertebral column as a whole.

The movements permitted in the vertebral column are: flexion or forward bending, extension or backward bending, bending to one or other side (usually termed lateral flexion), rotation and circumduction.

In *flexion* the anterior longitudinal ligament is relaxed and the anterior parts of the intervertebral discs are compressed; while at the limit of the movement the posterior longitudinal ligament, the ligamenta flava, and the interspinous and supraspinous ligaments are stretched, as well as the posterior fibres of the intervertebral discs. The interspaces between the laminae are widened, and the inferior articular processes glide upwards upon the superior articular processes of the subjacent

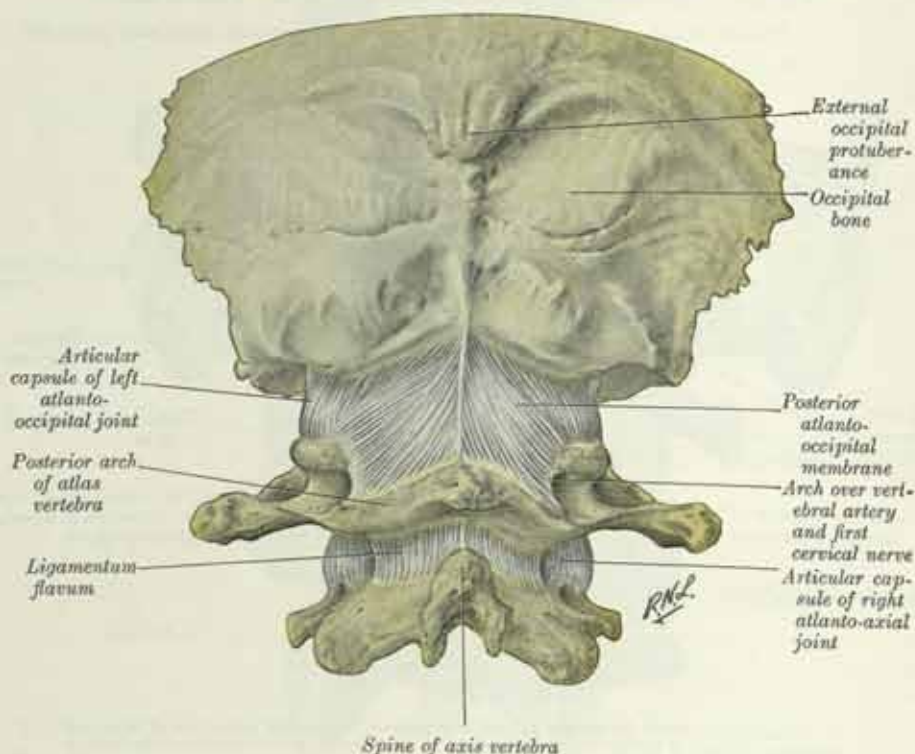
vertebræ. It should be remembered, however, that tension of the extensor muscles of the back is the most important factor in limiting the movement. Flexion is most extensive in the cervical region.

In *extension* an exactly opposite disposition of the parts takes place.* This movement is limited by the tension of the anterior longitudinal ligament, and by the approximation of the spines. It is free in the cervical and lumbar regions, but is restricted in the thoracic region.

In *lateral flexion* the sides of the intervertebral discs are compressed, the extent of motion being limited by the resistance offered by the tension of the antagonist muscles and the surrounding ligaments. It is always associated with some degree of rotation. Lateral movements may take place in any part of the column, but are freest in the cervical and lumbar regions.

Circumduction is limited, and is merely a succession of the preceding movements.

FIG. 492.—The atlanto-occipital and atlanto-axial joints, viewed from behind.



Rotation is produced by the twisting of the vertebræ on the intervertebral discs; this, although only slight between any two vertebræ, allows of a considerable extent of movement when it takes place in the whole length of the column, the front of the upper part of the column being turned to one or other side. This movement occurs to a slight extent in the cervical region, is freer in the upper part of the thoracic region, and is least in the lumbar region.

The extent and variety of the movements are influenced by the shape and direction of the articular facets. In the *cervical* region the upward inclination of the superior articular facets allows of free flexion and extension. Extension can usually be carried farther than flexion; at the upper end of the region it is checked by the locking of the posterior edges of the superior atlantal facets in the condylar fossæ of the occipital bone; at the lower end it is limited by a mechanism whereby the inferior articular processes of the seventh cervical vertebra slip into grooves behind and below the superior articular processes of the first thoracic vertebra. Flexion is

* P. Wiles (*Proc. of the Roy. Soc. of Medicine*, 28, 1935) is of opinion that in full extension the axis of movement lies just behind the articular processes and that it moves forwards as the column is straightened until, in full flexion, it passes through, approximately, the middle of the vertebral body.

The *intercornual ligaments* connect the cornua of the sacrum and coccyx on each side.

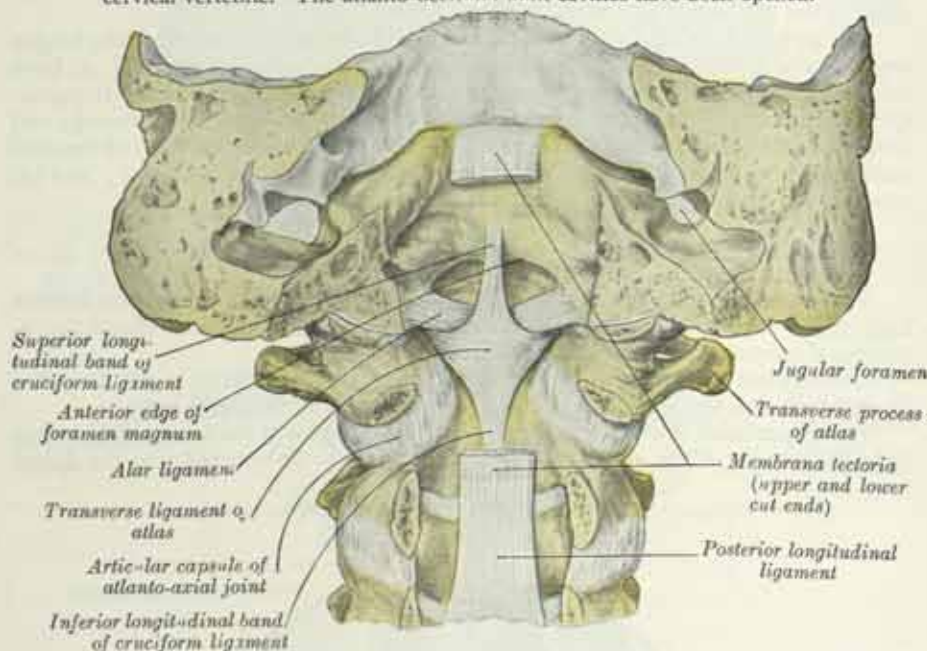
A **lateral sacrococcygeal ligament** exists on each side and connects the transverse process of the coccyx to the inferior lateral angle of the sacrum ; it completes the foramen for the fifth sacral nerve.

A thin disc of **fibrocartilage** is interposed between the contiguous surfaces of the sacrum and coccyx ; it is somewhat thicker in front and behind than at the sides. Occasionally the coccyx is freely movable on the sacrum ; in such cases an articular capsule lined with synovial membrane is present.

In the young subject the different segments of the coccyx are connected together by the extension downwards of the ventral and dorsal sacrococcygeal ligaments, thin anular discs of fibrocartilage being interposed between the segments. In the adult male, all the pieces become ossified together at a comparatively early period ; but in the female, this does not commonly occur until a later period of life. At a more advanced age the joint between the sacrum and coccyx is obliterated.

Backward and forward movements take place between the sacrum and coccyx ; their extent increases during pregnancy.

FIG. 494.—The atlanto-occipital and atlanto-axial joints, shown from behind after removal of the posterior part of the occipital bone and the laminae of the upper cervical vertebrae. The atlanto-occipital joint cavities have been opened.



4. THE ATLANTO-AXIAL JOINTS

The articulation of the atlas with the axis is of a complicated nature and comprises three synovial joints. Of these one is placed on each side between the inferior facet of the lateral mass of the atlas and the superior facet of the axis : the other is median in position and is placed between the dens and the anterior arch of the atlas.

The **lateral atlanto-axial joints** are plane joints, but the *articular surfaces* involved are both slightly convex in their long axes.

The fibrous capsules are thin and loose ; they surround the joints and are lined with synovial membrane. Each is strengthened at its posterior and medial part by an *accessory ligament*, which is attached below to the body of the axis near the base of the dens, and above to the lateral mass of the atlas near the transverse ligament.

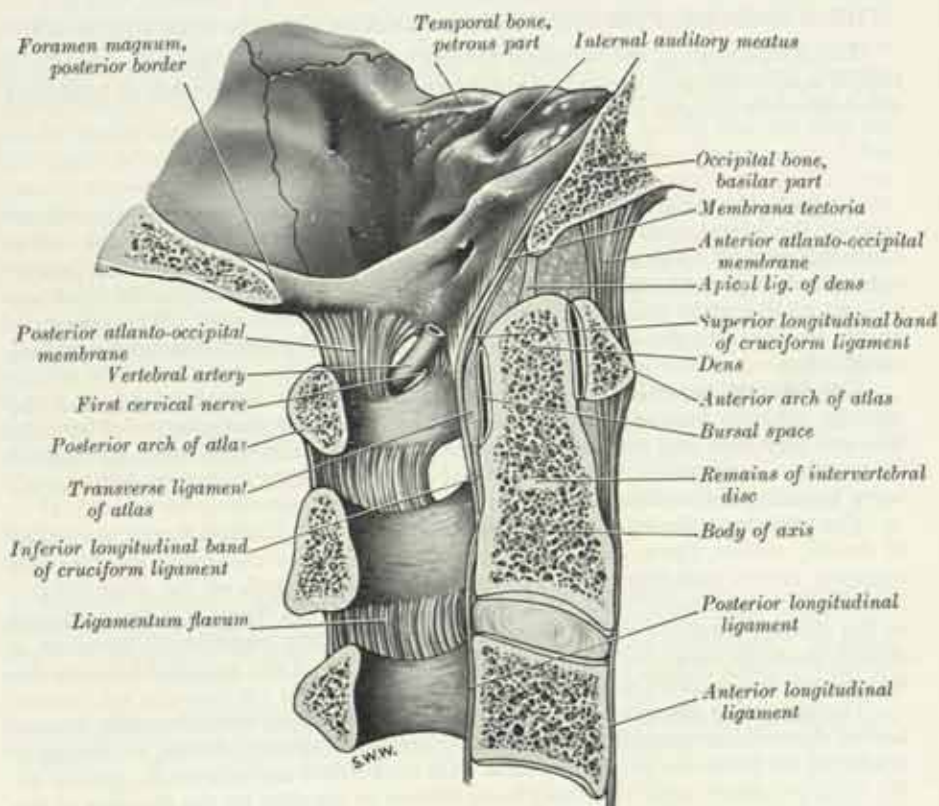
In front the two vertebrae are connected by a continuation of the anterior longitudinal ligament (fig. 491). In this position it is a strong membrane, fixed above to the lower border of the anterior arch of the atlas, and below to the front of the body of the axis. It is strengthened in the median plane by a rounded cord which connects the tubercle on the anterior arch of the atlas to the body of the axis.

Behind, the atlas and axis are joined by a broad, thin membrane (fig. 492) attached above to the lower border of the posterior arch of the atlas, below to the upper edges of the laminae of the axis; it is in series with the ligamenta flava and is pierced near its lateral extremity by the second cervical nerve.

The **median atlanto-axial joint** is a pivot-joint between the dens of the axis and the ring formed by the anterior arch and the transverse ligament of the atlas; the *articular surfaces* are reciprocally curved.

The fibrous capsule is weak and loose and is lined with synovial membrane. A second synovial cavity is present and lies between the transverse ligament of the atlas and the posterior surface of the dens (fig. 495): it is often continuous with the joint cavity of one or other of the atlanto-occipital joints.

FIG. 495.—A median sagittal section through the occipital bone and the first three cervical vertebrae.



The **transverse ligament of the atlas** (figs. 493-495) is a thick, strong band which arches across the ring of the atlas and retains the dens in contact with the anterior arch. It is broader in the middle than at the ends, and firmly attached on each side to a small tubercle on the medial surface of the lateral mass of the atlas. The median part of its anterior surface is covered by a thin layer of articular cartilage. As it crosses the dens, a small longitudinal band is prolonged upwards, and another downwards, from its superficial or posterior fibres. The upper band is attached to the upper surface of the basilar part of the occipital bone between the apical ligament of the dens and the membrana tectoria; the lower band, which may be absent, is attached to the posterior surface of the body of the axis; hence the whole ligament forms a cross and is named the *cruciform ligament of the atlas*. The transverse ligament divides the ring of the atlas into two unequal parts (fig. 493): of these, the posterior and larger surrounds the spinal medulla and its membranes; the anterior and smaller contains the dens. The neck of the process is constricted where it is embraced posteriorly by the transverse ligament, so that this ligament suffices to retain the dens in position after all the other ligaments have been divided.

Movements.—Movement must occur at all three joints at the same time, and it allows the rotation of the atlas (and with it the skull) upon the axis, the extent of rotation being limited by the alar ligaments (p. 471).

The opposed articular facets of the atlas and axis are both slightly convex in their long axes, as already stated. When, therefore, the upper facet glides forwards on the lower it also descends. The stretching of the fibres of the fibrous capsule that would result from this forward movement is diminished owing to the contemporaneous descent of their upper attachments, and in this way excessive laxity of the capsule is obviated.

Muscles producing the movements.—The principal muscles by which these movements are produced are the obliquus capitis inferior, the rectus capitis posterior major and the splenius capitis of one side, acting with the sternocleidomastoid muscle of the other side.

THE JOINTS OF THE VERTEBRAL COLUMN WITH THE CRANIUM

The articulation of the vertebral column with the cranium involves not only a pair of atlanto-occipital joints and their ligaments, but also a number of ligaments which connect the axis with the occipital bone.

1. THE ATLANTO-OCCIPITAL JOINTS

On each side the atlanto-occipital joint is placed between the superior articular facet of the lateral mass of the atlas and the condyle of the occipital bone: it is condyloid in type. The *articular surfaces* are reciprocally curved, but do not exactly correspond, as the atlantal facet may be constricted or occasionally subdivided into two, an arrangement which facilitates the lubrication of the joint. The bones are united by the articular capsules and the anterior and posterior atlanto-occipital membranes.

The **fibrous capsules** surround the condyles of the occipital bone and the superior articular facets of the atlas. They are thickened posteriorly and laterally but are very thin and sometimes deficient medially where the synovial cavities frequently communicate with the synovial bursa between the dens and the transverse ligament of the atlas.*

The **anterior atlanto-occipital membrane** (fig. 491) is broad, and composed of densely woven fibres which pass between the anterior margin of the foramen magnum above, and the upper border of the anterior arch of the atlas below; laterally it is continuous with the capsular ligaments; in front, it is strengthened in the median plane by the continuation of the anterior longitudinal ligament, a strong, rounded cord which connects the basilar part of the occipital bone to the tubercle on the anterior arch of the atlas (fig. 491).

The **posterior atlanto-occipital membrane** (fig. 492), broad but thin, is connected above to the posterior margin of the foramen magnum; below, to the upper border of the posterior arch of the atlas. On each side it arches over the groove for the vertebral artery, and with this groove bounds an opening for the entrance of the artery and the exit of the first cervical nerve. The free border of the membrane, arching over the artery and nerve, is sometimes ossified.

Movements.—The long axes of the two joints are set obliquely and run from behind forwards and medially. As a result of this obliquity and of the curvature of the occipital condyle, the corresponding articular surfaces of the two sides are in reality portions of the surface of an ellipsoid, the long axis of which is set transversely. The two joints therefore act as one, and movement may occur around transverse and anteroposterior axes, but not round a vertical axis. The movements permitted therefore are (a) flexion and extension, which give rise to the ordinary forward and backward nodding of the head, and (b) slight lateral motion to one or other side.

Muscles producing the movements:

Flexion.—Longus capitis and Rectus capitis anterior.

Extension.—Recti capitis posteriores major et minor, Obliquus superior, Semispinalis capitis, Splenius capitis, and Trapezius (upper fibres)

Lateral flexion.—Rectus capitis lateralis, Semispinalis capitis, Splenius capitis, Sternocleidomastoid and Trapezius (upper fibres).

* For details see A. J. E. Cave, *J. Anat. Lond.*, 68, 1934.

2. THE LIGAMENTS CONNECTING THE AXIS WITH THE OCCIPITAL BONE

Membrana tectoria. Two alar. Apical ligament.

The **membrana tectoria** (figs. 494, 495) is situated within the vertebral canal. It is a broad, strong band, which covers the dens and its ligaments and appears to be a prolongation upwards of the posterior longitudinal ligament of the vertebral column. It consists of superficial and deep lamellae, both of which are attached below to the posterior surface of the body of the axis. The superficial lamella expands as it ascends and is attached above to the upper surface of the basilar part of the occipital bone, in front of the foramen magnum, blending with the cranial dura mater. The deep lamella consists of a median band which extends to the basilar part of the occipital bone and two lateral bands which ascend on the medial sides of the atlanto-occipital joints to the margins of the foramen magnum.

The **alar ligaments** (fig. 494) are two strong, rounded cords, which arise one on each side of the upper part of the dens, and passing obliquely upwards and laterally, are inserted into rough impressions on the medial sides of the condyles of the occipital bone. The alar ligaments are relaxed on extension of the head but become taut on flexion and help to limit the movement. They are so disposed that they would render free rotation of the head impossible, were it not for the fact that the movement of rotation is accompanied by a slight descent of the atlas (p. 470). This descent causes sufficient relaxation of the alar ligaments to compensate for the tension brought about by rotation. Rotation to the right is eventually checked by the tension of those fibres of the right alar ligament which are attached to the dens in front of the axis of movement, and by tension of those fibres of the left alar ligament which are attached to the process behind the axis of movement. Rotation to the left is checked by the opposite fibres on each side.

The **apical ligament of the dens** (fig. 495), which extends from the tip of the process to the anterior margin of the foramen magnum, lies between the alar ligaments, being intimately blended with the deep portion of the anterior atlanto-occipital membrane and with the upper longitudinal band of the cruciform ligament of the atlas. It is regarded as a rudimentary intervertebral disc, and may contain traces of the notochord in its substance.

It must be remembered that, in addition to the ligaments which unite the atlas and axis to the skull, the *ligamentum nuchæ* (p. 464) connects the cervical vertebrae with the cranium.

Applied Anatomy.—Dislocation of the atlas from the axis, with rupture of the transverse ligament of the atlas and consequent injury to the spinal medulla, is the mode in which death is produced in many cases of execution by hanging. Hanging may however produce a fracture through the axis, or a separation through the disc between the axis and the third cervical vertebra. Following infective conditions of the pharynx or in its vicinity, the cruciform ligament may become softened and occasionally a pathological dislocation of the atlas on the axis may result.

THE COSTOVERTEBRAL JOINTS

The articulations of the ribs with the vertebral column may be divided into two sets, one connecting the heads of the ribs with the bodies of the vertebrae, the other uniting the necks and tubercles of the ribs with the transverse processes.

1. THE JOINTS OF THE HEADS OF THE RIBS (fig. 496)

These articulations constitute a series of plane joints. They are formed by the articulation of the heads of the typical ribs with the facets on the contiguous margins of the bodies of the thoracic vertebrae, and with the intervertebral discs between them. The first, tenth, eleventh, and twelfth ribs each articulate with a single vertebra; in each of the other joints, an intra-articular ligament divides the joint cavity into two distinct parts. The ligaments of the joints are:

Articular capsule. Radiate. Intra-articular.

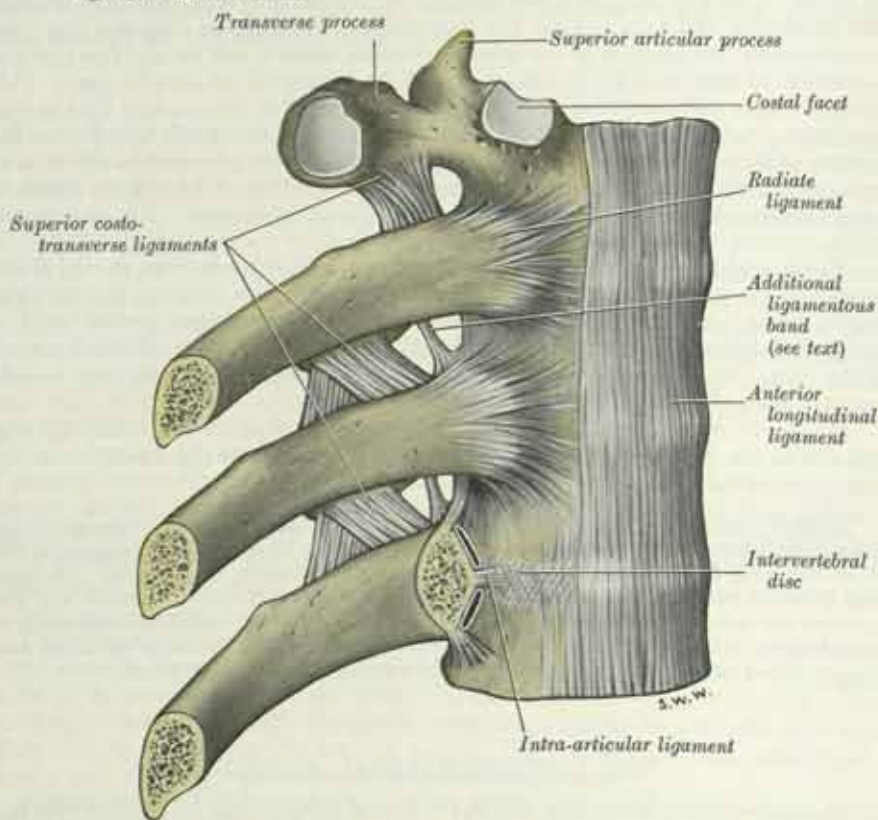
The **fibrous capsules** connect the heads of the ribs with the circumferences

of the articular cavities formed by the intervertebral discs and the adjacent vertebræ. Some of their upper fibres pass through the intervertebral foramen to the back of the intervertebral disc, while the posterior fibres are continuous with the costo-transverse ligament.

The **radiate ligament** connects the anterior part of the head of each rib with the sides of the bodies of two vertebræ, and the intervertebral disc between them. It is attached to the anterior part of the head of the rib, just beyond the articular surface. The superior fibres ascend and are connected with the body of the vertebra above; the inferior fibres descend to the body of the vertebra below; the middle fibres, the smallest and least distinct, are horizontal and attached to the intervertebral disc.

In the articulation of the first rib, the radiate ligament is attached to the body of the last cervical vertebra, as well as to that of the first thoracic. In the articulations

FIG. 496.—The costovertebral joints. Right anterolateral aspect. In the lowest joint shown most of the radiate ligament and the anterior part of the head of the rib have been excised to show the two joint cavities and the intra-articular ligament between them.



of the tenth, eleventh and twelfth ribs, each of which articulates with a single vertebra, the radiate ligament is connected to the vertebra with which the rib articulates, and also to the vertebra immediately above it.

The **intra-articular ligament** is situated in the interior of the joint. It consists of a short band of fibres, flattened from above downwards, attached laterally to the crest separating the two articular facets on the head of the rib, and medially to the intervertebral disc; it divides the joint into two cavities. In the joints of the first, tenth, eleventh and twelfth ribs, intra-articular ligaments do not exist; consequently, there is but one cavity in each of these articulations.

2. THE COSTOTRANSVERSE JOINTS (fig. 497)

The articular portion of the tubercle of a rib forms a plane joint with the transverse process of the vertebra to which it corresponds numerically. In the eleventh

and twelfth ribs this articulation is wanting. In the upper six (or five) joints the *articular surfaces* are reciprocally curved, but in the lower joints the surfaces are flattened (p. 260).

The ligaments of the joints are :

Articular capsule.

Superior costotransverse.

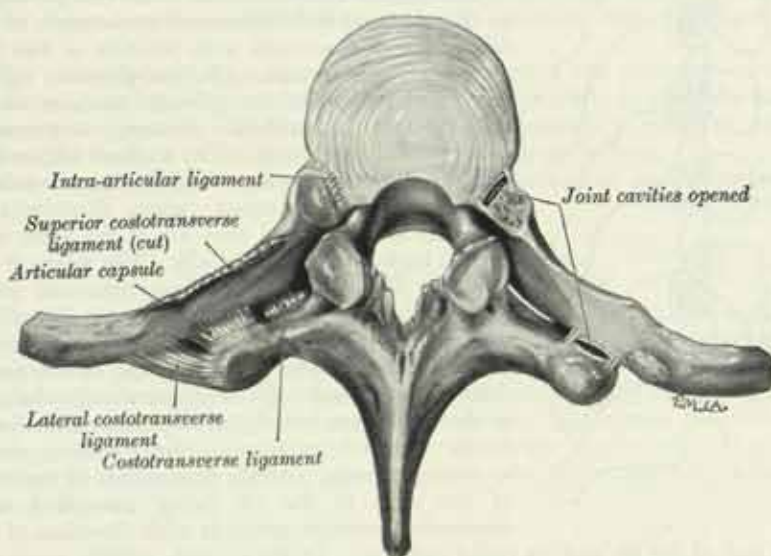
Costotransverse.

Lateral costotransverse.

The **fibrous capsule** is a thin membrane attached to the circumference of the articular surfaces, and lined with synovial membrane.

The **superior costotransverse ligament** comprises an anterior and a posterior layer. The anterior fibres are attached below to the crest of the neck of the rib and pass upwards and laterally to the lower border of the transverse process immediately above (fig. 496). Laterally they are continuous with the fibres of the internal intercostal membrane, and they are crossed anteriorly by the corresponding

FIG. 497.—The costovertebral joints, viewed from above.



intercostal vessels and nerve. The posterior fibres are attached to the posterior surface of the neck of the rib and run upwards and medially behind the anterior fibres to reach the transverse process immediately above. Laterally they are related to the external intercostal muscle.

The first rib has no superior costotransverse ligament. The neck of the twelfth rib is connected to the base of the transverse process of the first lumbar vertebra by a band of fibres, named the *lumbocostal ligament*; it is in series with the superior costotransverse ligaments.

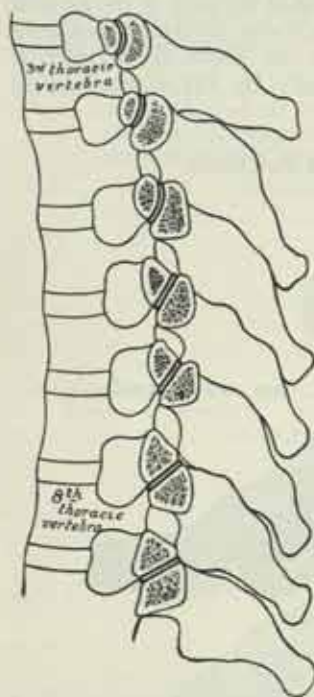
An additional ligamentous band is usually present, although it is somewhat variable in its disposition. It is attached to a depression above and medial to the tubercle of the rib and, passing medial to the superior costotransverse ligament, it reaches the back of the inferior articular process, often sending a few fibres upwards to the base of the transverse process. Through the interval between this band and the medial border of the superior costotransverse ligament (fig. 496), the dorsal ramus of the corresponding thoracic nerve runs backwards with its accompanying vessels.

The **costotransverse ligament** consists of short but strong fibres, connecting the rough surface on the back of the neck of the rib with the anterior surface of the adjacent transverse process. A rudimentary ligament may be present at the eleventh and twelfth ribs.

The **lateral costotransverse ligament** is a short, thick, strong fasciculus, which passes obliquely from the apex of the transverse process to the rough non-

articular portion of the tubercle of the rib. The ligaments attached to the upper ribs ascend from the transverse processes; they are shorter and more oblique than those attached to the lower ribs, which descend slightly.

FIG. 498.—A section through the costotransverse joints from the third to the ninth inclusive. Contrast the concave facets on the upper with the flattened facets on the lower transverse processes.



Movements.—The heads of the ribs are so closely connected to the bodies of the vertebrae by the radiate and intra-articular ligaments that only slight gliding movements of the articular surfaces on one another can take place. Similarly, the strong ligaments binding the necks and tubercles of the ribs to the transverse processes limit the movements of the costotransverse joints to slight gliding, the nature of which is determined by the shape and direction of the articular surfaces (fig. 498). The articular surfaces on the tubercles of the upper six ribs are oval in shape and convex from above downwards; they fit into corresponding concavities on the anterior surfaces of the transverse processes, so that upward and downward movements of the tubercles are associated with rotation of the rib-neck on its long axis. On the seventh, eighth, ninth and tenth ribs the articular surfaces of the tubercles are flat, and face obliquely downwards, medially and backwards. The surfaces with which they articulate are placed on the upper aspects of the transverse processes; when, therefore, the tubercles are drawn up they are at the same time carried backwards and medially. The joints of the heads of the ribs and the costotransverse joints move simultaneously and in the same directions, the total effect being that the neck of the rib moves as if on a single joint, of which the two articulations form the ends. In the upper six ribs the neck of the rib moves but slightly upwards and downwards; its chief movement is one of rotation round its own long axis, rotation downwards of the front of the neck of the rib being associated with depression, rotation upwards with elevation of the

anterior end of the rib and its costal cartilage. In the seventh, eighth, ninth and tenth ribs the neck of the rib moves upwards, backwards and medially, or downwards, forwards and laterally, with resultant increase or diminution of the infrasternal angle; very slight rotation accompanies these movements.

Muscles producing the movements.—These are discussed with the movements of respiration (p. 588).

THE STERNOCOSTAL JOINTS (fig. 499)

The first costal cartilage is directly united to the sternum by a cartilaginous joint. The cartilages of the remaining true ribs usually articulate with the sternum by synovial joints. The articular cavity is, however, frequently absent, particularly in the lower members of this series of joints. The articular surfaces are covered with fibrocartilage which also unites the costal cartilages to the sternum when joint cavities are absent.*

The ligaments of the synovial joints are :

Articular capsule.

Radiate sternocostal.

Intra-articular.

Costoxiphoid.

The **fibrous capsules** surround the joints between the sternum and the cartilages of the ribs from the second to the seventh inclusive. They are very thin,

* D. J. Gray and E. D. Gardner, *Anat. Rec.*, 87, 1943.

intimately blended with the sternocostal ligaments, and strengthened at the upper and lower parts of the articulations by a few fibres which connect the cartilages to the side of the sternum.

The **radiate sternocostal ligaments** are broad, thin, membranous bands which radiate from the front and back of the sternal ends of the cartilages of the true ribs to the anterior and posterior surfaces of the sternum. Their superficial fibres intermingle with the fibres of the ligaments above and below them, with those of the opposite side, and on the front of the sternum with the tendinous fibres of origin of the pectoralis major, forming a thick fibrous membrane which envelops the bone, and is more distinct at its lower part than at its upper part.

The **intra-articular ligaments** are constantly present only between the second costal cartilages and the sternum. The cartilage of the *second rib* is connected with the sternum by means of an intra-articular ligament, attached laterally to the cartilage of the rib, and medially to the fibrocartilage which unites the manubrium and body of the sternum. Occasionally the cartilage of the *third rib* is connected with the first and second pieces of the body of the sternum by an intra-articular ligament. Fibrocartilaginous strands connecting the articular surfaces are frequently present in the third and succeeding joints of the series. Absence of articular cavities between the costal cartilages and the sternum may be found at all ages.

The **costoxiphoid ligaments** connect the anterior and posterior surfaces of the seventh costal cartilage, and sometimes those of the sixth, to the front and back of the xiphoid process. They vary in length and breadth in different subjects; those on the back of the joint are less distinct than those in front.

Movements.—Slight gliding movements are permitted in the sternocostal joints.

THE INTERCHONDRAL JOINTS (fig. 499)

The contiguous borders of the sixth and seventh, the seventh and eighth, and the eighth and ninth costal cartilages articulate with each other by small smooth, oblong facets. Each articulation is enclosed in a thin *fibrous capsule*, lined with synovial membrane and strengthened laterally and medially by *interchondral ligaments*, which pass from one cartilage to the other. Sometimes the fifth costal cartilages, more rarely the ninth, articulate by their lower borders with the adjoining cartilages by small, oval facets; more frequently the connexion is by a few ligamentous fibres.

THE COSTOCHONDRAL JOINTS

The lateral end of each costal cartilage is received into a depression in the sternal end of the rib, and the two are enveloped by the periosteum.

THE STERNAL JOINTS

The manubriosternal joint.—In the majority of cases the joint between the manubrium and the body of the sternum is cartilaginous in character, the bony surfaces being coated with hyaline cartilage and connected by a disc of fibrocartilage, which may become ossified in the adult. In rather more than thirty per cent. of subjects the central part of the disc undergoes absorption and the joint is converted into a synovial one. The two segments of the bone are also connected by the fibrous membrane which envelops the bone.

The xiphisternal joint.—The joint between the xiphoid process and the body of the sternum is also a secondary cartilaginous joint, but it is usually converted into a synostosis by the fifteenth year.

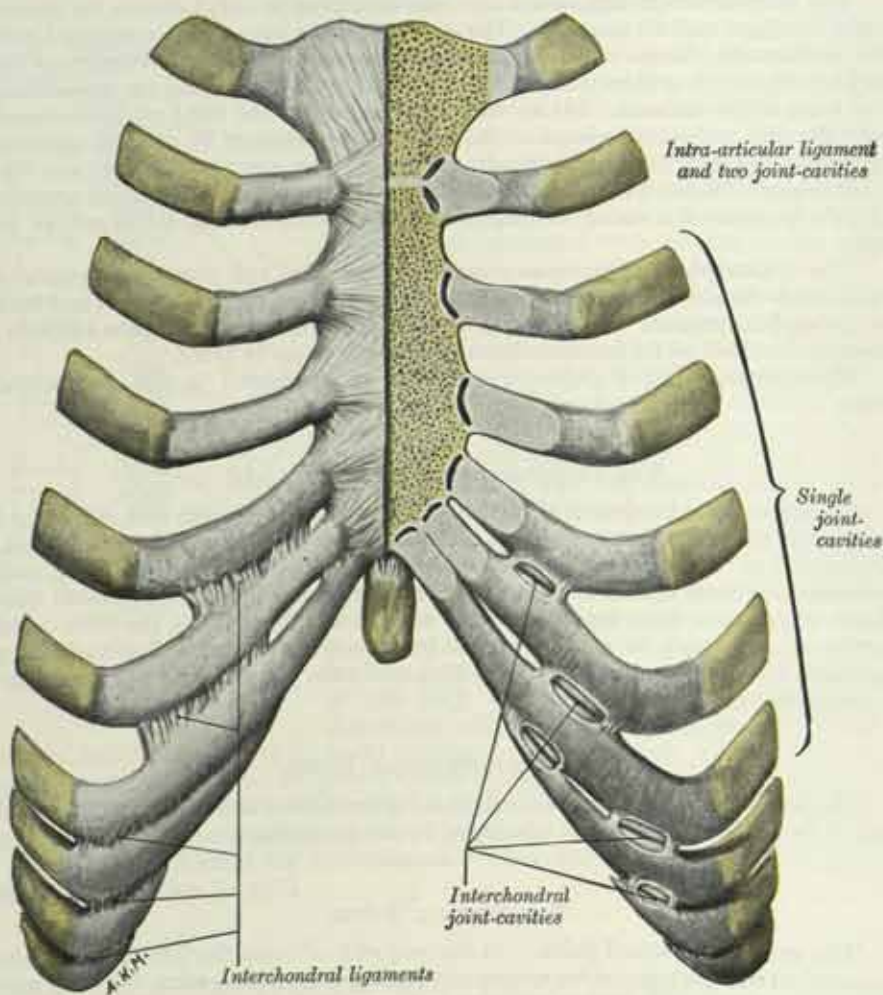
THE MECHANISM OF THE THORAX

Each rib possesses its own range and variety of movements, but the movements of all are combined in the respiratory excursions of the thorax. Each rib may be regarded as a lever, the fulcrum of which is situated immediately outside the costo-

transverse articulation, so that when the shaft of the rib is elevated the neck is depressed, and *vice versa*; from the disproportion in length of the arms of the lever a slight movement at the vertebral end of the rib is greatly magnified at the anterior extremity.

The anterior ends of the ribs lie on a lower plane than the posterior; and, therefore, when the shaft of the rib is elevated, the anterior extremity is also thrust forwards. Again, the middle of the shaft of the rib lies in a plane below that passing

FIG. 499.—The sternocostal and interchondral joints, viewed from in front.



through the two extremities, so that when the shaft is elevated relatively to its ends it is at the same time carried outwards from the median plane; further, each rib forms the segment of a curve which is greater than that of the rib immediately above. Therefore the elevation of a rib increases the transverse diameter of the thorax in the plane to which it is raised. The modifications of the rib movements at their vertebral ends have already been described (p. 474). Further modifications result from the attachments of their anterior extremities, and it is convenient therefore to consider separately the movements of the ribs of the three groups—vertebrosternal, vertebrochondral, and vertebral.

Vertebrosternal ribs (fig. 500).—The first rib differs from the others of this group in that its attachment to the sternum is a rigid one; this is counter-balanced to some extent by the fact that its head possesses no intra-articular ligament, and is therefore more movable. The first pair of ribs with the manubrium sterni move as a

single piece, the anterior portions being elevated by rotatory movements at the vertebral extremities. In normal quiet respiration the movement of this arc is practically *nil*; when it does occur the anterior part is raised and carried forwards, increasing the anteroposterior diameter of this region of the chest. The movement of the second rib is also slight in normal respiration, as its anterior extremity is fixed to the manubrium, and therefore prevented from moving upwards. The sterno-costal articulation, however, allows the middle of the shaft of the rib to be drawn up, and in this way the transverse thoracic diameter is increased. Elevation of the third, fourth, fifth, and sixth ribs raises and thrusts forwards their anterior extremities, the greater part of the movement being effected by the rotation of the rib-neck backwards. The thrust of the anterior extremities carries forwards and upwards the body of the sternum, which moves on the joint between it and the manubrium, and thus the anteroposterior thoracic diameter is increased. This movement, however, is soon arrested, and the elevating force is then expended in raising the middle part

FIG. 500.—A diagram showing the axes of movement (AB and CD) of a vertebro-sternal rib. The interrupted lines indicate the position of the rib in inspiration.

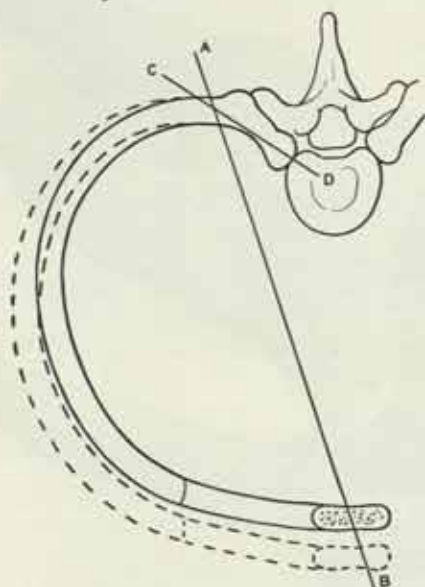
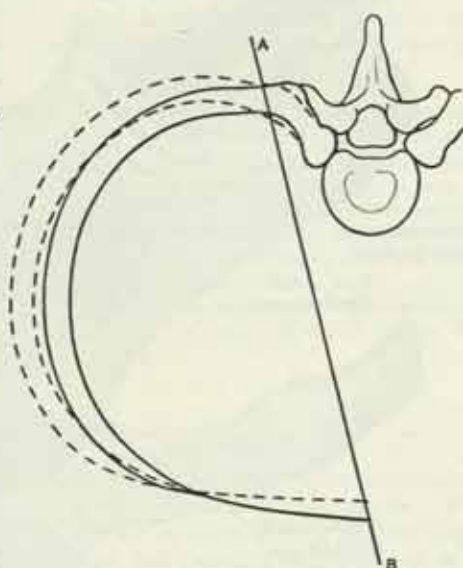


FIG. 501.—A diagram showing the axes of movement (AB) of a vertebro-chondral rib. The interrupted lines indicate the position of the rib in inspiration.



of the shaft of the rib and everting its lower border; at the same time the costo-chondral angle is opened out. By these latter movements a considerable increase in the transverse diameter of the thorax is effected.

Vertebrochondral ribs (fig. 501).—The seventh rib is included with this group, as it conforms more closely to their type. While the movements of these ribs assist in enlarging the thorax for respiratory purposes, they are also concerned in increasing the upper abdominal space for viscera displaced by the action of the diaphragm. The costal cartilages articulate with one another, so that each pushes up that above it, the final thrust being directed to pushing forwards and upwards the lower end of the body of the sternum. The amount of elevation of the anterior extremities is limited on account of the very slight rotation of the rib-neck. Elevation of the shaft is accompanied by an outward and backward movement; the outward movement everts the anterior end of the rib and opens up the infracostal angle, while the backward movement pulls back the anterior extremity and counteracts the forward thrust due to its elevation; this latter is most noticeable in the lower ribs, which are the shortest. The total result is a considerable increase in the transverse and a diminution in the median anteroposterior diameter of the upper part of the abdomen; at the same time, however, the lateral anteroposterior diameters of the abdomen are increased.

Vertebral ribs.—Since these ribs have free anterior extremities and only costo-vertebral articulations with no intra-articular ligaments, they are capable of slight movements in all directions. When the other ribs are elevated these are depressed and fixed to form points of action for the diaphragm.

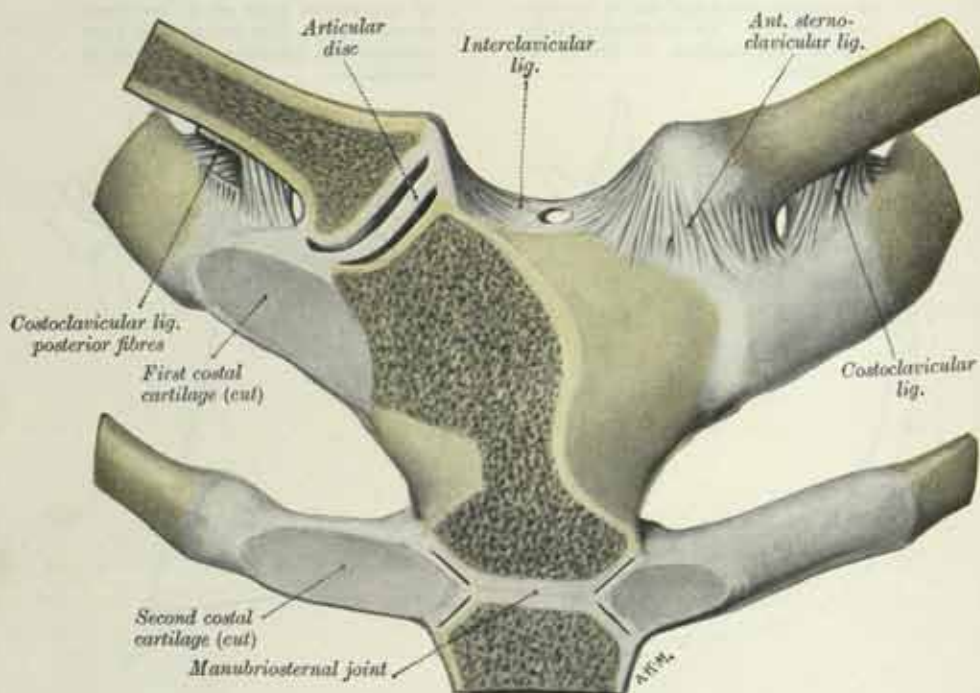
Muscles producing the movements.—These are discussed with the movements of respiration (p. 588).

THE JOINTS OF THE UPPER LIMB GIRDLE

I. THE STERNOCLAVICULAR JOINT (fig. 502)

The parts entering into the formation of the sternoclavicular joint are the sternal end of the clavicle, the clavicular notch of the manubrium sterni, and the cartilage

FIG. 502.—The sternoclavicular joints, viewed from in front.



of the first rib. The *articular surface* of the clavicle is much larger than that of the sternum, and is covered with a layer of fibrocartilage which is considerably thicker than that on the sternum. It is convex in its vertical diameter, and slightly concave anteroposteriorly. The clavicular notch of the sternum is reciprocally curved, but the two surfaces are not perfectly congruent; the joint cavity is completely subdivided by an articular disc.

Articular capsule.
Anterior sternoclavicular.
Posterior sternoclavicular.

Interclavicular.
Costoclavicular.

The **fibrous capsule** surrounds the articulation; in front and behind, it is of considerable thickness, but above, and especially below, it is thin and partakes more of the character of areolar tissue than of true fibrous tissue.

The **anterior sternoclavicular ligament** is a broad band, covering the anterior surface of the joint; it is attached above to the upper and front part of the sternal end of the clavicle, and, passing obliquely downwards and medially, is attached below to the front of the upper part of the manubrium sterni.

The **posterior sternoclavicular ligament** is a weaker band which covers the posterior aspect of the joint. It is attached to the posterior aspect of the sternal end of the clavicle and passes obliquely downwards and medially to be attached to the back of the upper part of the manubrium sterni.

The **interclavicular ligament** is continuous above with the deep cervical fascia; it passes from the upper part of the sternal end of one clavicle to that of the other, but gives some fibres to the upper margin of the manubrium sterni.

The **costoclavicular ligament** is short, flat, strong, and rhomboid in form. Attached below to the upper surface of the cartilage of the first rib, it is fixed above to the impression on the under surface of the medial end of the clavicle. The anterior fibres are directed upwards, backwards and laterally, the posterior fibres upwards, backwards and medially (fig. 502).

The **articular disc** is flat and nearly circular, and is interposed between the articulating surfaces of the sternum and clavicle. It is attached, above, to the upper and posterior border of the articular surface of the clavicle; below, to the cartilage of the first rib, near its junction with the sternum; and by the rest of its circumference to the fibrous capsule. It is thicker at the circumference—especially at its upper and posterior part—than at the centre, and divides the joint into two cavities.

The *arteries* supplying the joint are derived from the internal thoracic and suprascapular arteries; the *nerves*, from the anterior supraclavicular nerves and the nerve to the subclavius muscle.

Applied Anatomy.—The strength of this joint depends upon its ligaments, and especially on the articular disc. It is owing to these, and to the fact that the force of the blow is usually transmitted along the long axis of the clavicle, that dislocation rarely occurs, and that the clavicle is broken rather than displaced. Dislocation may be either forwards, backwards or upwards. Should the clavicle be displaced backwards it may cause pressure on the trachea and great vessels of the neck. Owing to the shape of the articular surfaces, and the fact that the strength of the joint mainly depends upon the ligaments, the displacement when reduced is very liable to recur.

The joint is the fulcrum for the leverage exerted by the trapezius on the clavicle in elevation of the shoulder. If the joint is unstable, as the result of a dislocation, the effectiveness of the muscle is appreciably diminished.

II. THE ACROMIOCLAVICULAR JOINT (Plate VI)

The acromioclavicular articulation (fig. 506) is a plane joint between the acromial end of the clavicle and the medial margin of the acromion of the scapula. The *articular surface* of the acromial end of the clavicle is covered with fibrocartilage, and forms a narrow, oval area, which is directed downwards and laterally so as to overlap the corresponding area on the medial border of the acromion. The long axis of the joint lies in an anteroposterior plane. Its ligaments are:

Articular capsule.
Acromioclavicular.

Coracoclavicular { Trapezoid part.
Conoid part.

The **fibrous capsule** completely surrounds the articular margins, and is strengthened above by the acromioclavicular ligament.

The **acromioclavicular ligament** is a quadrilateral band, covering the superior part of the joint, and extending between the upper part of the acromial end of the clavicle and the adjoining part of the upper surface of the acromion; it is composed of parallel fibres, which interlace with the aponeuroses of the trapezius and deltoid muscles.

An **articular disc** is usually found in this joint; when present, it occupies the upper part of the articulation, and only partially separates the articular surfaces. More rarely, it divides the joint completely into two cavities.

The **coracoclavicular ligament** (fig. 503) connects the clavicle with the coracoid process of the scapula. It does not properly belong to the acromioclavicular joint, but is usually described with it since it forms a most efficient means of preventing the clavicle from losing contact with the acromion. It consists of two parts, viz. *trapezoid* and *conoid*, which are usually separated by a bursa.

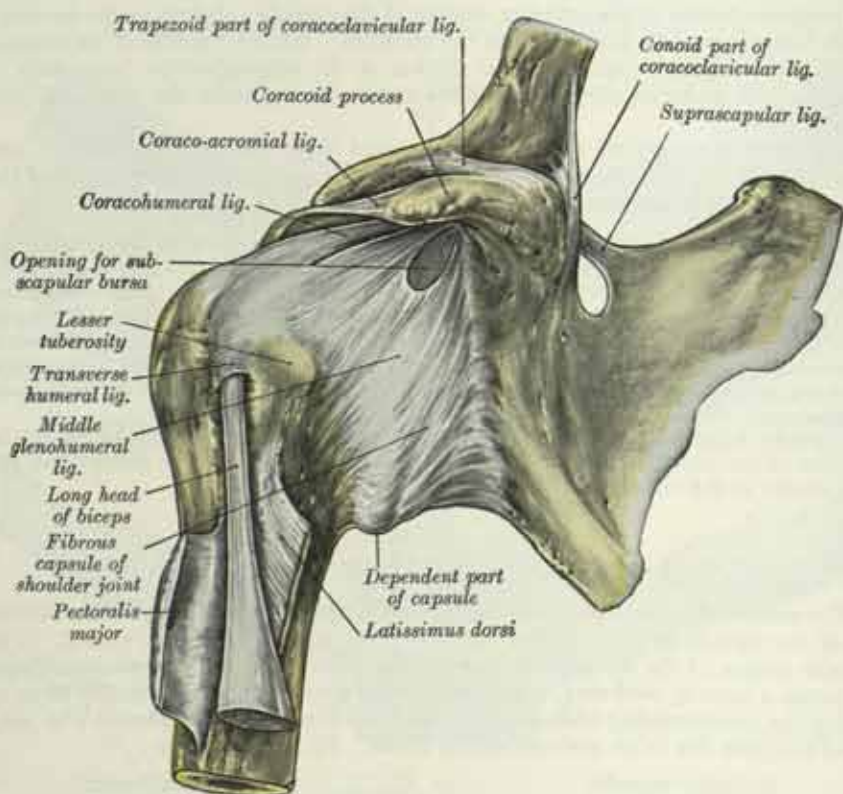
The *trapezoid part*, which forms the anterior and lateral fasciculus, is broad, thin,

and quadrilateral. It is attached, below, to the upper surface of the coracoid process; above, to the trapezoid line on the under surface of the clavicle. The ligament runs almost horizontally. Its anterior border is free; its posterior is joined with the conoid part, the two forming, by their junction, an angle projecting backwards.

The *conoid part*, which forms the posterior and medial fasciculus, is a dense band of fibres, triangular in form, with its base directed upwards. Its apex is attached to the medial and posterior edge of the root of the coracoid process just in front of the scapular notch; its base is fixed to the conoid tubercle on the under surface of the clavicle, and to a line proceeding medially from it for a short distance.

The *arteries* supplying the acromioclavicular joint are derived from the suprascapular and thoraco-acromial arteries; the *nerves* from the suprascapular and lateral pectoral nerves.

FIG. 503.—The right shoulder joint. Anterior aspect.



Movements of the shoulder girdle.—The movements which occur at the sternoclavicular and acromioclavicular joints are always associated with movements of the scapula, and movements of the scapula are usually, though not invariably, associated with movements of the humerus at the shoulder joint. The movements of the scapula and clavicle *per se* are of academic interest only, but they are of great practical importance when they are considered from the point of view of their relation to the movements of the humerus. The student, therefore, is advised to keep this in mind when reading the following paragraphs, and, on their conclusion, he should turn to the paragraphs dealing with the movements at the shoulder joint itself (p. 486).

The acromioclavicular joint allows the acromion to glide forwards and backwards, and to rotate upwards and downwards on the clavicle, but the range of these scapular movements is greatly increased by associated movements which occur at the sternoclavicular joint at the same time. The analysis of all these movements can be effected by a study of the movements of the scapula.

The following movements of the scapula are permitted: (1) elevation and

depression; (2) forward and backward movement round the chest wall; (3) rotation forwards (or upwards) and rotation backwards (or downwards).

(1) *Elevation or depression of the scapula*, e.g. shrugging of the shoulders, does not necessarily imply any corresponding movement at the shoulder joint.

(a) During elevation only a slight degree of angular movement occurs at the acromioclavicular joint, but the sternal end of the clavicle, which moves round an anteroposterior axis passing through the bone above the attachment of the medial end of the costoclavicular ligament, rotates downwards over the surface of the articular disc. This movement at the sternoclavicular joint is checked by tension of the antagonist muscles, the costoclavicular ligament and the lower part of the capsule. It is brought about by the *trapezius (upper fibres)* and the *levator scapulae*, and, as these muscles tend to rotate the scapula in opposite directions, a pure upward movement is effected.

(b) In the reverse movement a little angular movement occurs at the acromioclavicular joint, but at the sternoclavicular joint the clavicle rotates upwards on the disc, and this movement is checked by tension of the antagonist muscles, and by the interclavicular and sternoclavicular ligaments and the articular disc. As a rule this movement is carried out with the help of gravity, but it can be performed actively by the *serratus anterior (lower fibres)* and the *pectoralis minor*.

(2) (a) *Forward movement of the scapula* round the chest wall occurs in all forward-pushing, thrusting and punching movements, and it is usually accompanied by some degree of forward rotation. The acromion moves forwards over the clavicular facet to the limit of its range of movement, and at the same time the point of the shoulder is advanced further by a forward movement of the lateral end of the clavicle. This forward movement is associated with a backward swing of the sternal end of the bone, which moves backwards over the sternal facet, carrying the articular disc with it. Tension of the antagonist muscles, of the posterior sternoclavicular ligament and of the posterior fibres of the costoclavicular ligament checks this backward movement. The *serratus anterior* and the *pectoralis minor* are the prime movers, and this combination ensures the continuous apposition of the medial border of the scapula with the chest wall. In addition, the 'strap' effect of the upper fibres of the latissimus dorsi keeps the inferior angle in close contact with the ribs, both in this movement and in forward rotation.

(b) In *backward movement of the scapula*, such as occurs when the shoulders are braced back, the reverse movements take place and they are checked at the sternoclavicular joint by tension of the anterior sternoclavicular ligament and of the anterior fibres of the costoclavicular ligament. When it is carried out actively or against resistance, the *trapezius* and the *rhomboid muscles* are the prime movers.

It may be noted here that when force is applied at the extremity of the outstretched arm, e.g. by a fall on the hand, the pressure transmitted to the glenoid cavity tends to drive the sloping acromial facet below the acromial end of the clavicle, but at the same time it causes tension of the trapezoid ligament, which serves to resist the displacement.

(3) (a) *Forward rotation of the scapula* serves to increase the range of movement of the humerus, by turning the bone so that the glenoid cavity faces almost directly upwards—the position which it assumes when the arm is raised above the head. This movement is always associated with some degree of elevation of the humerus and is accompanied by some forward movement of the scapula round the chest wall. The acromial facet rotates upwards on the clavicle and at the same time the point of the shoulder is raised. The rotation results in tension of the conoid ligament at a relatively early stage and thereafter the clavicular attachment of the ligament appears to serve as the centre around which the subsequent movement takes place. Thus throughout the greater part of the movement the conoid ligament is kept taut and it helps to bring about the upward rotation of the clavicle around its long axis which occurs in the later stages of elevation of the arm above the head. This rotatory movement of the clavicle is limited in extent (40° - 45° *) and is checked by the tension of the articular disc, the sternoclavicular capsule and the costoclavicular ligament.

In this important movement the *trapezius* and the *serratus anterior* are the prime movers.

* V. T. Inman, J. B. de C. M. Saunders and L. C. Abbott, *J. Bone and Joint Surg.*, 26, 1944.

(b) The opposite rotation is usually effected under the influence of gravity, and the gradual relaxation of the trapezius and serratus anterior is sufficient to bring it about. When it is performed actively, the *levator scapulae*, the *rhomboids*, and, in the initial stages at least, the *pectoralis minor* are the prime movers so far as the scapula is concerned.

In all the movements of the scapula the *subclavius muscle* serves to steady the clavicle by drawing it medially and downwards.

Attention should be drawn to the fact that muscles which are antagonists for one type of movement may nevertheless combine together and act as prime movers for another, for it is movements and not individual muscles that are represented in the motor cortex of the cerebrum (p. 1041). Thus the serratus anterior and the trapezius are opposed in forward and backward movements of the scapula round the chest wall, but combine together as prime movers for forward rotation of the bone.

THE LIGAMENTS OF THE SCAPULA

The ligaments of the scapula (fig. 503) are the coraco-acromial, and the transverse scapular.

The **coraco-acromial ligament** is a strong triangular band, extending between the coracoid process and the acromion. Its apex is attached to the edge of the acromion just in front of the articular surface for the clavicle; and its base to the whole length of the lateral border of the coracoid process. This ligament, together with the coracoid process and the acromion, forms an arch for the protection of the head of the humerus. It sometimes consists of two strong marginal bands and a thinner intervening portion.

When the *pectoralis minor* is inserted, as it is occasionally, into the capsule of the shoulder joint instead of into the coracoid process, the tendon of the muscle passes between the two bands of the coraco-acromial ligament.

The **transverse scapular ligament** converts the scapular notch into a foramen, and is sometimes ossified. It is a thin and flat fasciculus, narrower at the middle than at the extremities, which are attached to the base of the coracoid process and the medial end of the scapular notch respectively. The suprascapular nerve runs through the foramen; the suprascapular vessels cross over the ligament.

A weak, membranous band, often termed the *spinoglenoid ligament*, stretches from the lateral border of the spine of the scapula to the margin of the glenoid cavity. It forms an arch under which the suprascapular nerve and vessels enter the infraspinous fossa. It is frequently absent.

JOINTS OF THE UPPER LIMB—I. THE SHOULDER JOINT (Plates VI and VII)

The shoulder joint (figs. 503 to 507) is a ball-and-socket joint. The bones entering into its formation are the hemispherical head of the humerus and the shallow glenoid cavity of the scapula, a construction which permits of very considerable movement but seriously affects the stability of the joint. Structurally the shoulder joint is weak, since, for such strength as it possesses, it is dependent on the support given by the muscles which surround it and not on its bony conformation or the presence of any strong ligaments. It is, however, protected above by an arch, formed by the coracoid process, the acromion and the coraco-acromial ligament.

The *articular surfaces* are reciprocally curved, but as the head of the humerus is much larger than the glenoid cavity only a portion of it can be in contact with the cavity in any given position of the joint. The glenoid cavity is deepened somewhat by a fibrocartilaginous rim attached to its margins and termed the *glenoid labrum*. Both articular surfaces are covered with a layer of hyaline cartilage; that on the head of the humerus is thickest at its centre and thinner peripherally, while the reverse is the case in the glenoid cavity. When the arm is by the side the anterior edge of the glenoid cavity can be represented on the front of the shoulder by a line, 3 cm. long, drawn downwards from a point just lateral to the tip of the coracoid process. This line, which should be very slightly concave laterally, lies over the lower half of the joint.

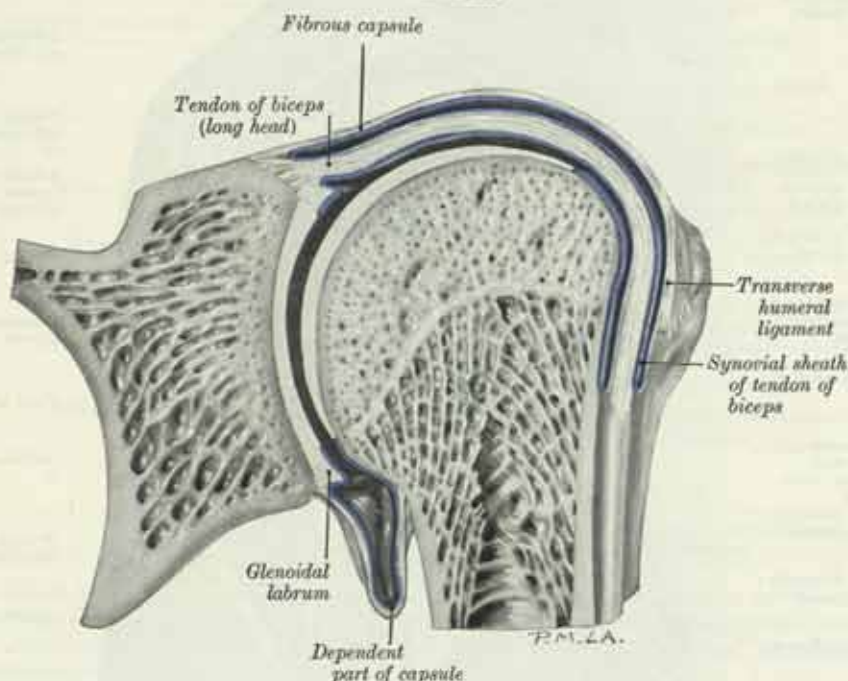
The ligaments of the articulation are :

Articular capsule.
Coracohumeral.

Glenoidal labrum.
Transverse humeral.

The **fibrous capsule** (figs. 503, 504) envelops the joint, and is attached, medially, to the circumference of the glenoid cavity beyond the glenoidal labrum; above, it encroaches on to the root of the coracoid process so as to include the origin of the long head of the biceps within the joint. Laterally it is attached to the anatomical neck of the humerus, except on the medial side where it descends for rather more than 1 cm. on to the shaft of the bone. It is so remarkably loose and lax that the bones may be separated from each other for a distance of 2 or 3 cm., an evident provision for the great freedom of movement which is permitted at this articulation. *It should be noted, however, that this separation can be effected only after the superior*

FIG. 504.—A section through the shoulder joint. The synovial membrane is shown in blue.



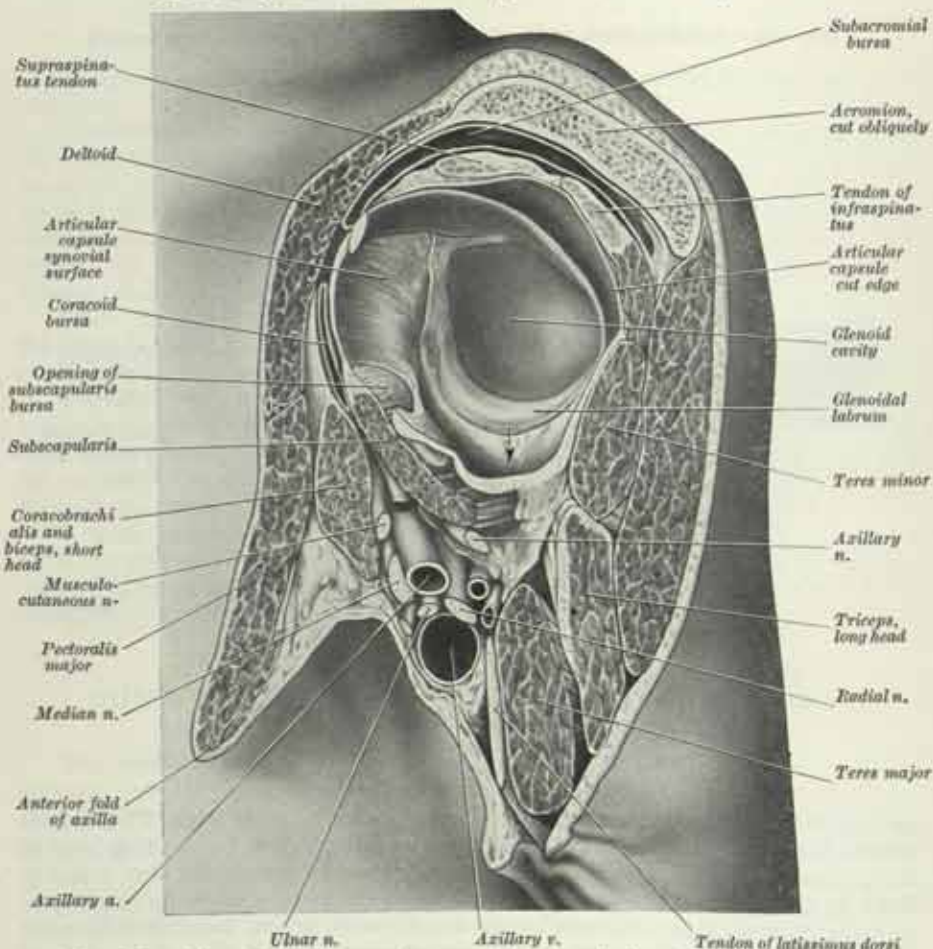
part of the ligament has been relaxed by some degree of abduction. The fibrous capsule is strengthened, above, by the supraspinatus; below, by the long head of the triceps; behind, by the tendons of the infraspinatus and teres minor; and in front, by the tendon of the subscapularis. The tendons of the subscapularis, supraspinatus, infraspinatus, and teres minor are all more or less completely blended with the fibrous capsule, and this arrangement increases the value of the support which they supply. The relationship of the long head of the triceps is not so intimate, for it is separated from the inferior part of the capsule by the axillary nerve and the posterior circumflex humeral vessels as they pass backwards on leaving the axilla (fig. 507). It is the inferior part of the capsule, therefore, which is least supported, and *it is just this part which is subjected to the greatest strain, because it is stretched tightly across the rounded head of the humerus when the arm is abducted.*

There are usually two, occasionally three, openings in the capsule. One, situated anteriorly, below the coracoid process, establishes a communication between the joint and a bursa behind the tendon of the subscapularis; another, placed between the tuberosities of the humerus, gives passage to the long tendon of the biceps and its synovial sheath; the third, which is not constant, is at the posterior part, between the joint and a bursal sac under the tendon of the infraspinatus.

Three supplemental bands (fig. 506) named the *glenohumeral ligaments*, strengthen the capsule. These are best seen by opening the joint from behind and removing the head of the humerus. At their scapular ends they are all attached to the upper part of the medial margin of the glenoid cavity and are intimately connected with the glenoidal labrum. The superior band passes along the medial edge of the tendon of biceps and is attached to a small depression above the lesser tuberosity of the humerus; the middle band reaches to the lower part of the lesser tuberosity; the inferior band extends to the lower part of the anatomical neck of the humerus. In addition to these, the capsule is strengthened in front by two bands, one derived from the tendon of the pectoralis major, the other from the tendon of the teres major.

FIG. 505.—An obliquely coronal section through the left shoulder and shoulder joint, dissected after removal of the upper limb.

The arrow points to the dependent part of the articular capsule.



Note.—The relations of the axillary vessels to each other and to the branches of the brachial plexus as displayed in this dissected section may be misleading, and the reader is referred to fig. 707 for the usual view.

The *synovial membrane* lines the inner surface of the fibrous capsule, and covers the lower part and sides of the anatomical neck of the humerus as far as the articular cartilage on the head of the bone. The tendon of the long head of the biceps passes through the joint and is enclosed in a tubular sheath of synovial membrane, which is continued round the tendon into the bicipital groove as far as the surgical neck of the humerus (figs. 503, 504).

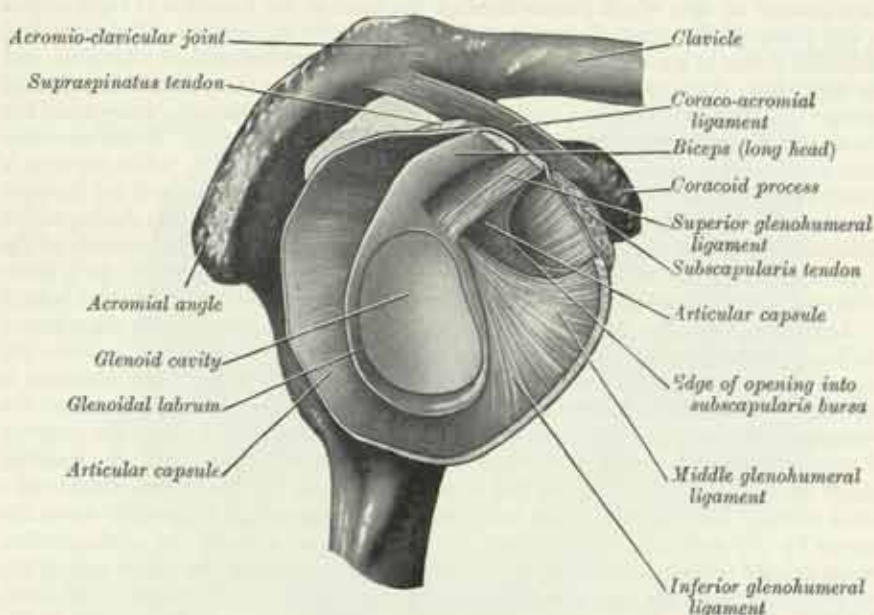
The *coracohumeral ligament* (fig. 503) is a broad band which strengthens the upper part of the capsule. It is attached to the lateral border of the root of the coracoid process, and passes obliquely downwards and laterally to the front of the greater tuberosity of the humerus, blending with the tendon of the supraspinatus.

The posterior and lower border of the ligament is united to the fibrous capsule; its anterior and upper border is free, and overlaps it.

The **transverse humeral ligament** (fig. 503) is a broad band passing from the lesser to the greater tuberosity of the humerus; it converts the bicipital groove into a canal, and its attachment lies above the epiphysial line. The transverse humeral ligament functions simply as a retinaculum for the tendon of the long head of the biceps muscle.

The **glenoidal labrum** (fig. 505) is a fibrocartilaginous rim attached round the margin of the glenoid cavity. It is triangular on section, the base being fixed to the circumference of the cavity, while the free edge is thin and sharp. It is continuous above with the tendon of the long head of the biceps, which gives off two fasciculi

FIG. 506.—Interior of the right shoulder joint. Viewed from the antero-lateral aspect.



to blend with the fibrous tissue of the labrum. It deepens the articular cavity, and protects the edges of the bone. Its attachment to the margin of the glenoid cavity is sometimes deficient in parts, and a small fringe of the synovial membrane occasionally protrudes through the gap.

Bursæ.—The bursæ in the neighbourhood of the shoulder joint are the following: (1) one between the tendon of the subscapularis and the joint-capsule (fig. 506): it communicates with the joint cavity through an opening situated between the superior and the middle glenohumeral ligaments; (2) one is sometimes found between the tendon of the infraspinatus and the capsule; it occasionally opens into the joint; (3) the *subacromial bursa* (fig. 505), lies between the deltoid and the capsule; it does not communicate with the joint, but is prolonged under the acromion and coraco-acromial ligament, and intervenes between them and the supraspinatus; (4) one on the upper surface of the acromion; (5) one is frequently found between the coracoid process and the capsule; (6) one sometimes exists behind the coracobrachialis; (7) one between the *teres major* and the long head of the triceps; (8) one in front of, and another behind, the tendon of the *latissimus dorsi*.

The *muscles* in relation with the joint are, above, the supraspinatus; below, the long head of the triceps; in front, the subscapularis; behind, the infraspinatus and *teres minor*; within, the tendon of the long head of the biceps. The deltoid covers the joint in front, behind and laterally (fig. 505).

The *arteries* supplying the joint are derived from the anterior and posterior circumflex humeral, and suprascapular arteries.

The *nerves* of the joint are derived mainly from the suprascapular, axillary and the lateral pectoral nerves. The suprascapular supplies the superior and

posterior parts of the articular capsule, the axillary, the inferior and anterior parts and the lateral pectoral the anterior and superior parts.*

Movements.—The shoulder is a ball-and-socket joint, and therefore is capable of flexion, extension, abduction, adduction, circumduction and rotation. The laxity of its articular capsule and the large size of the head of the humerus compared with that of the shallow glenoid cavity give to the shoulder a wider range of movement than is possible at any other joint.

When the movements at the shoulder joint are being analysed, the humerus should be considered in its relationship to the scapula and not in its relationship to the sagittal and coronal planes of the trunk. When the arm is by the side in the resting position, the glenoid cavity faces almost equally forwards and laterally, and the position of the humerus corresponds to that of the scapula, although relative to the trunk it appears to be rotated medially (p. 371). As a result flexion carries the arm forwards and medially across the front of the chest, and the movement takes place around an axis which passes through the head of the humerus at right angles to the plane of the glenoid cavity at (approximately) its centre. Abduction and adduction occur in a plane at right angles to the plane of flexion and extension, and the axis passes through the head of the humerus parallel to the plane of the glenoid cavity.† Abduction therefore carries the arm forwards and laterally away from the trunk, and the movement occurs in the plane of the body of the scapula. At the shoulder joint itself the movement of abduction varies from 100° to 120° ;‡ when the arm is raised vertically above the head an additional 55° to 65° are obtained by forward rotation of the scapula (p. 481). It must be emphasised, however, that during active elevation of the arm the movement at the shoulder joint and the movements of the scapula and clavicle occur simultaneously—except in the initial stages (25° – 30°), when most and in some cases the whole of the movement takes place at the shoulder joint.§

In flexion, however, the humerus moves in a plane at right angles to the plane of the body of the scapula, and no amount of rotation of the scapula can increase the degree of elevation (90°) obtained in full flexion. If the fully flexed humerus is gradually abducted, the degree of elevation increases *pro rata*, until, when the humerus comes to lie in the plane of the body of the scapula, i.e. when the position of true abduction is reached, the full 180° of elevation is obtained. In rotation, which may be medial or lateral, the humerus revolves for about one-quarter of a circle about a vertical axis. The range of rotatory movement is greatest when the arm is by the side, and least when it is raised to the vertical. In circumduction, which results from a succession of the foregoing movements, the lower end of the humerus describes the base of a cone, the apex of which is at the head of the bone, but this movement at the shoulder joint can be increased very substantially by the movements of the scapula, and the combination is well exemplified in the arm movements of a fast bowler in cricket.

The peculiar relation of the tendon of the long head of the biceps to the shoulder joint appears to subserve various purposes. By its connexion with both the shoulder and elbow the muscle harmonises the action of the two joints, and acts as an elastic ligament during all the movements which occur at these articulations. It strengthens the upper part of the shoulder joint, and helps to prevent the head of the humerus

* Gardner, E., *Anat. Rec.*, **102**, 1948.

† Many writers prefer to consider flexion and extension as occurring in a paramedian plane, and abduction and adduction as occurring in a coronal plane, i.e. they prefer to regard the movements as being relative to the trunk and not to the scapula. The reader is warned that, if he prefers to accept these definitions, he must regard the deltoid and supraspinatus muscles as producing a combination of flexion and abduction, for working as a combination they do not raise the arm in a coronal plane. When the humerus is raised to the vertical from a position of flexion (in this sense), it undergoes a process of medial rotation, for which the deltoid (anterior fibres), the subscapularis and, probably, the supraspinatus are responsible. In the same way when the humerus is raised to the vertical from the position of abduction (in this sense), it undergoes a process of lateral rotation. In both cases the effect of the rotation is to bring the humerus into the same position relative to the scapula as it occupies when the arm is raised to the vertical in the plane of the body of the scapula, i.e. the movement described in the text as true abduction. When the arm is elevated in a natural way from the side, the humerus moves throughout in the plane of the body of the scapula and undergoes no appreciable rotation. As a result, when the humerus is raised to the vertical position, the medial epicondyle is always directed forwards and slightly laterally. (C. P. Martin, *British Journal of Surgery*, **20**, 1932, and T. B. Johnston, *British Journal of Surgery*, **25**, 1937.)

‡ H. Flecker, *Med. J. Aust.*, 1929.

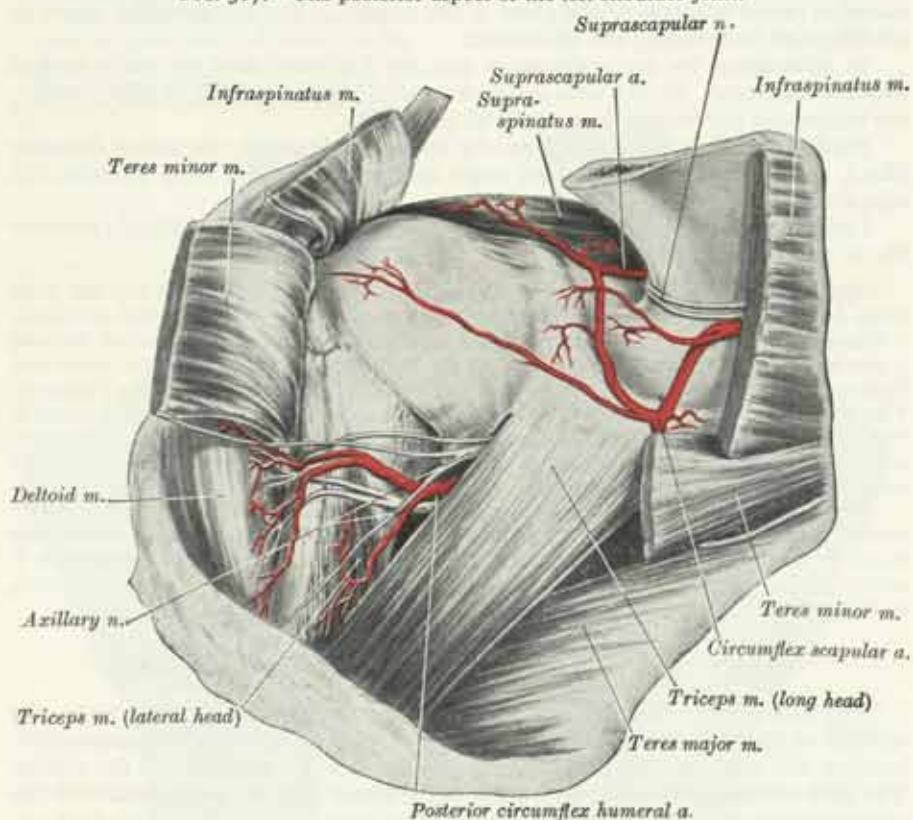
§ C. W. Cathcart, *J. Anat. and Phys.*, **18**, 1884, and R. D. Lockhart, *J. Anat. Lond.*, **64**, 1930.

from being pressed up against the acromion when the deltoid contracts (*vide infra*). By its passage along the bicipital groove it assists in steadying the head of the humerus in the various movements of the arm.

Owing to the shallowness of the glenoid cavity and the laxity of the capsule, a wide range of *accessory movements* (p. 457) is possible at the shoulder joint. The head of the humerus can be moved backwards, forwards, upwards and downwards in relation to the glenoid cavity and, when the arm is abducted—the position in which the accessory movements are most free—it can be separated from it by traction.

Muscles producing the movements.—The muscles moving the shoulder may be divided into: (a) those acting on the shoulder girdle and (b) those acting on the shoulder joint.

FIG. 507.—The posterior aspect of the left shoulder joint.



An oblique saw-cut has been made through the spine of the scapula and the acromion has been removed. Portions of the infraspinatus and teres minor muscles have been excised and their tendons have been turned forwards.

(a) **Muscles acting on the shoulder girdle.**—These muscles have already been considered in connexion with the movements of the shoulder girdle (p. 480).

(b) **Muscles acting on the shoulder joint.**—The principal muscles concerned in producing the movements of the shoulder joint, viz. the deltoid, pectoralis major, latissimus dorsi and teres major, are large and powerful and they act to considerable mechanical advantage on a joint which, owing to the shallowness of the glenoid cavity and the laxity of the articular capsule, is mechanically unstable. This serious disadvantage is counteracted perfectly by the stabilising influence of the short muscles inserted close to the upper end of the humerus, viz. the subscapularis, supraspinatus, infraspinatus and teres minor, for they function primarily as postural muscles to retain the head of the humerus in its correct alignment relative to the glenoid cavity and to obviate its tendency to skid during active movements.

In **flexion**, the *pectoralis major* (clavicular part) (p. 615), the *deltoid* (anterior fibres) and the *coracobrachialis* are the principal muscles concerned, but they are assisted by the biceps, and the *sternocostal part of the pectoralis major* plays an impor-

tant part when the arm is drawn forwards to the plane of the trunk from the fully extended position.

In **extension**, the *deltoid (posterior fibres)* and the *teres major* are the principal muscles concerned when the movement starts with the arm by the side, but, when the fully flexed arm is extended against resistance, the *latissimus dorsi* and the *sternocostal part of the pectoralis major* are powerful adjuvants until the arm reaches the plane of the body.

In **abduction** the *deltoid* is the prime mover, but it is to be noted that, in the initial stages, the force of the *deltoid* is exerted mainly in an upward direction and, unless opposed, would result in upward displacement of the head of the humerus. The *subscapularis*, *infraspinatus* and *teres minor* provide the opposing force by exerting downward traction on the head of the bone and these three muscles and the *deltoid* constitute a 'couple,'* the effect of which is to produce true abduction, i.e. elevation of the humerus in the plane of the scapula. The *supraspinatus* assists in effecting and maintaining the movement.

In **adduction** the *pectoralis major* and the *latissimus dorsi* are the principal muscles concerned, but the *teres major*, the *coracobrachialis* and, to a lesser extent, the biceps and the triceps (long head) all participate.

Medial rotation is brought about by the *pectoralis major*, the *deltoid (anterior fibres)*, the *latissimus dorsi*, the *teres major* and, when the arm is by the side, the *subscapularis*.

Lateral rotation is brought about by the *infraspinatus*, the *deltoid (posterior fibres)*, and the *teres minor*.

Applied Anatomy.—Owing to the construction of the shoulder joint and the wide range of movement which it enjoys, as well as in consequence of its exposed situation, it is more frequently dislocated than any other joint. Dislocation occurs when the arm is abducted. In that position the head of the humerus presses against the lower and front part of the capsule, which is the thinnest and least supported part of the ligament. The rent in the capsule almost invariably takes place in this situation, and through it the head of the bone escapes, so that the dislocation in most instances is primarily subglenoid. If, after the dislocation has been reduced, abduction of the arm is prevented, the dislocation cannot recur.

When the shoulder joint is ankylosed, the loss of movement in the joint is partly compensated for by increased mobility of the scapula. In treating conditions of the shoulder joint likely to lead to ankylosis, the humerus should be kept in the position it assumes when the palm of the hand is placed on the back of the neck, i.e. abducted, so as to make full use of this compensating mobility of the scapula.

II. THE ELBOW JOINT (Plates VIII and IX)

The elbow joint includes two articulations: (1) *humero-ulnar*, between the trochlea of the humerus and the trochlear notch of the ulna, and (2) *humero-radial*, between the capitulum of the humerus and the facet on the head of the radius. The joint cavity and the articular capsule of the elbow joint are continuous with the corresponding parts of the superior radio-ulnar joint, and these articulations are sometimes grouped together as the *cubital articulation*.

The *articular surfaces* concerned are the trochlea and capitulum of the humerus, on the one hand, and the trochlear notch of the ulna and the head of the radius, on the other. The trochlea is not a simple pulley, for its medial flange is much more extensive than its lateral flange and projects downwards to a lower level, so that the line of the joint, which lies 2 cm. below the line joining the two epicondyles, passes from the lateral side downwards and medially. In addition, the trochlea is widest where it covers the posterior aspect of the bone and in this position its lateral edge forms a salient ridge. The trochlear notch is by no means perfectly congruent with the trochlea. In full extension the medial part of its upper (olecranon) half is not in contact with the trochlea, and a corresponding strip on the lateral side loses contact on flexion. The olecranon and coronoid parts of the trochlear notch are usually separated by a narrow, roughened strip of bone, devoid of articular cartilage and covered with a little fibro-fatty tissue lined with synovial membrane. The capitulum and the head of the radius are reciprocally curved, but the best contact is obtained when the semiflexed radius is in the midprone position. The rim of the head fits into the groove between the capitulum and the trochlea.

* V. T. Inman, J. B. de C. M. Saunders, and L. C. Abbott, *J. Bone and Joint Surg.*, 26, 1944.

The humero-ulnar and humeroradial articulations together form a ginglymus or hinge-joint, the ligaments of which are :

Articular capsule.

Ulnar collateral.

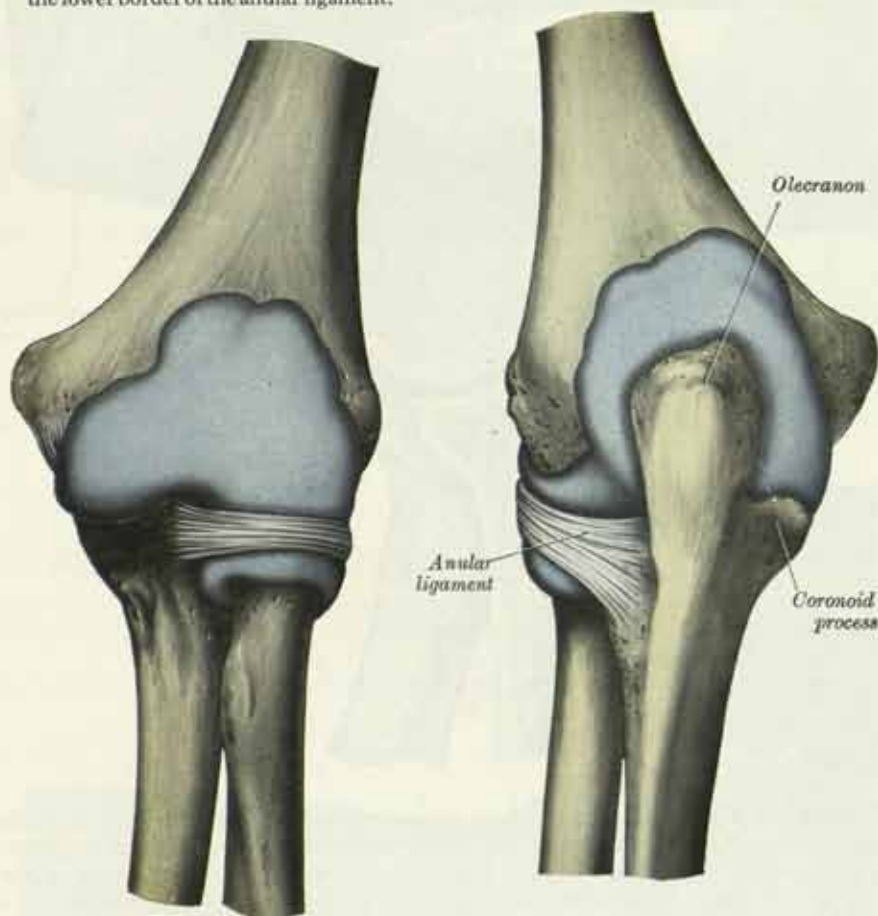
Radial collateral.

The **articular capsule** (figs. 510 and 512).—The anterior part of the *fibrous capsule* is a broad and thin fibrous layer. It is attached, above, to the front of the medial epicondyle and to the front of the humerus immediately above the coronoid

FIG. 508.—The synovial cavity of the left elbow joint, partially distended. Anterior aspect. (Originally drawn from a specimen prepared by J. C. B. Grant.)

The fibrous capsule of the elbow joint has been removed but the anular ligament has been left *in situ*. Note that the synovial membrane descends below the lower border of the anular ligament.

FIG. 509.—The synovial cavity of the left elbow joint, partially distended. Posterior aspect of the specimen represented in fig. 508.

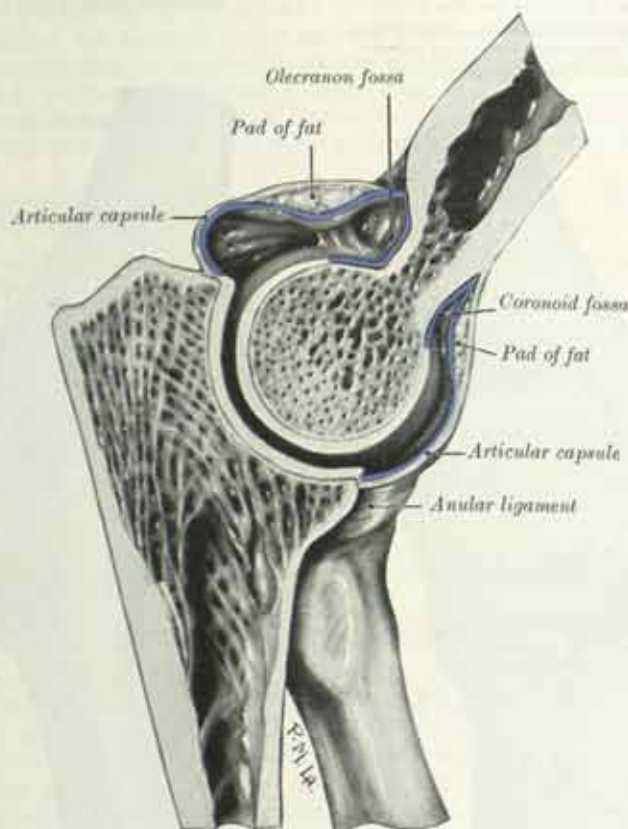


and radial fossæ ; below, to the anterior surface of the coronoid process of the ulna and to the anular ligament (p. 493), being continuous at the sides with the ulnar and radial collateral ligaments. Its superficial fibres pass obliquely from the medial epicondyle of the humerus to the anular ligament. The middle fibres, vertical in direction, pass from the upper part of the coronoid depression and become partly blended with the preceding, but are inserted mainly into the anterior surface of the coronoid process. The deep or transverse set intersects these at right angles. Anteriorly the fibrous capsule is in relation with the brachialis and receives numerous fibres from its deep surface.

The posterior part of the fibrous capsule is thin and membranous, and consists of transverse and oblique fibres. Above, it is attached to the humerus immediately behind the capitulum and close to the lateral margin of the trochlea, to the margins of the olecranon fossa, and to the back of the medial epicondyle some little distance from the trochlea. Below, it is fixed to the upper and lateral margins of the olecranon, to the posterior part of the anular ligament, and to the ulna behind the radial notch. It is in relation, behind, with the tendon of the triceps and the anconeus muscle.

The *synovial membrane* (figs. 508 to 510) is very extensive. It extends from the margin of the articular surface of the humerus, lines the coronoid, radial and olecranon fossæ on that bone and covers the flattened medial surface of the trochlea

FIG. 510.—A sagittal section through the left elbow joint. The synovial membrane is shown in blue.



(fig. 388); it is reflected over the deep surface of the fibrous capsule and lines the deep surface of the lower part of the anular ligament. Projecting into the joint-cavity between the radius and ulna from behind there is a crescentic fold of the synovial membrane, suggesting the division of the joint into two; one the humero-radial, the other the humero-ulnar. This fold is irregularly triangular in outline and contains a variable quantity of extrasynovial fat (fig. 513).

Between the fibrous capsule and the synovial membrane there are three other pads of fat. The largest, over the olecranon fossa, is pressed into the fossa by the triceps during flexion of the joint; the second, over the coronoid fossa, and the third, over the radial fossa, are pressed by the brachialis into their respective fossæ during extension. In addition, smaller tags of fat covered with synovial membrane project into the joint-cavity opposite to the constrictions on each side of the trochlear notch (p. 378), and cover the small non-articular areas of the bone in these situations.

The **ulnar collateral (medial) ligament of the elbow joint** (fig. 511) is a thick triangular band consisting of two portions, an anterior and a posterior, united by a

FIG. 511.—The left elbow joint. Viewed from the medial side.

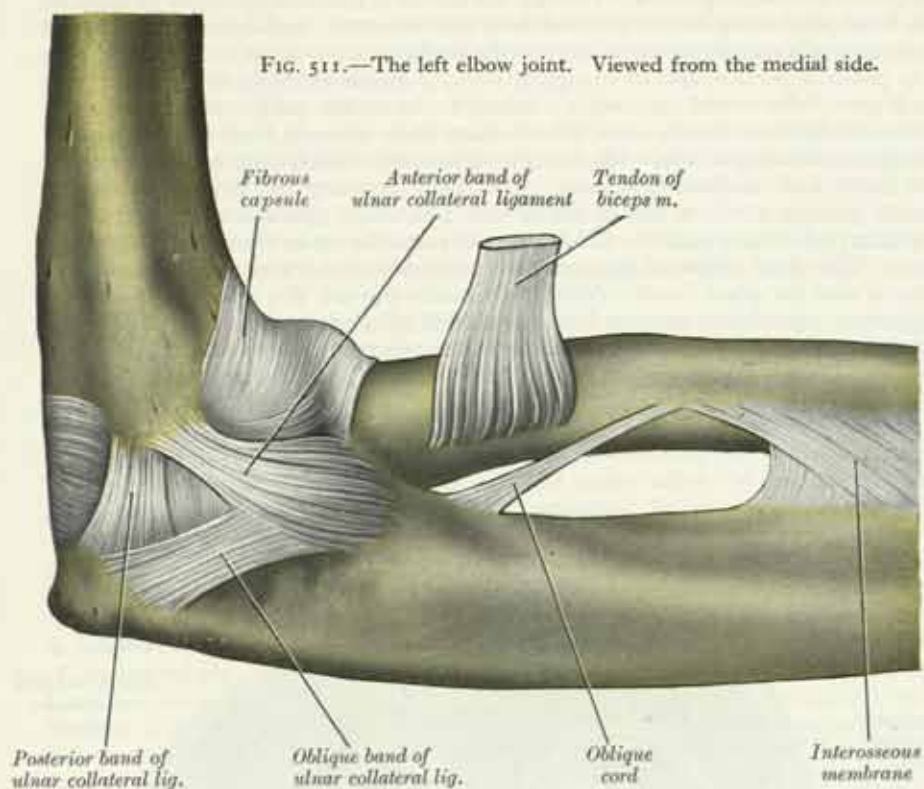
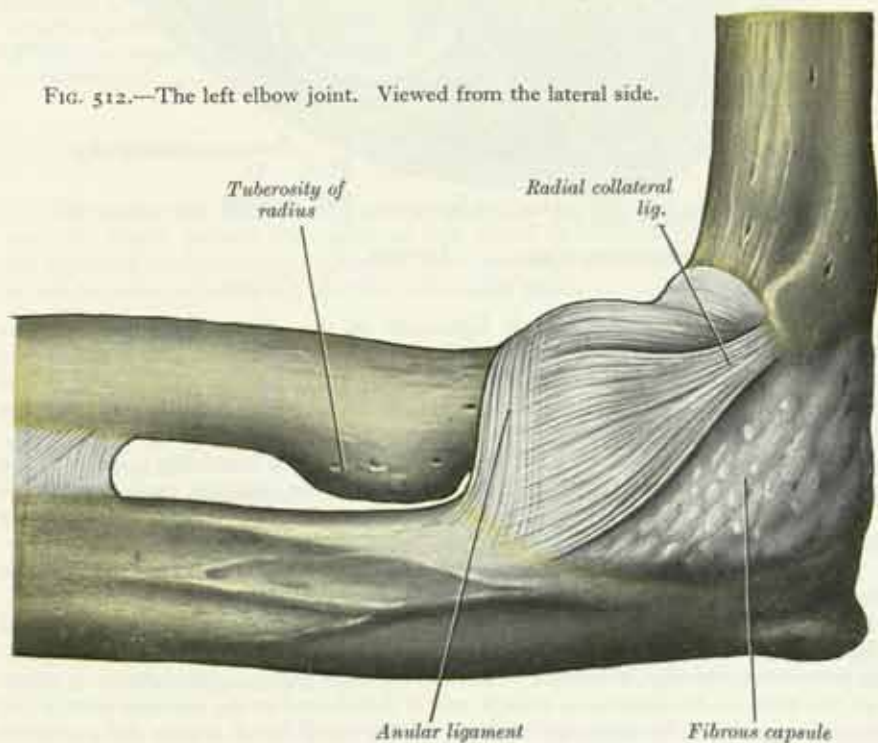
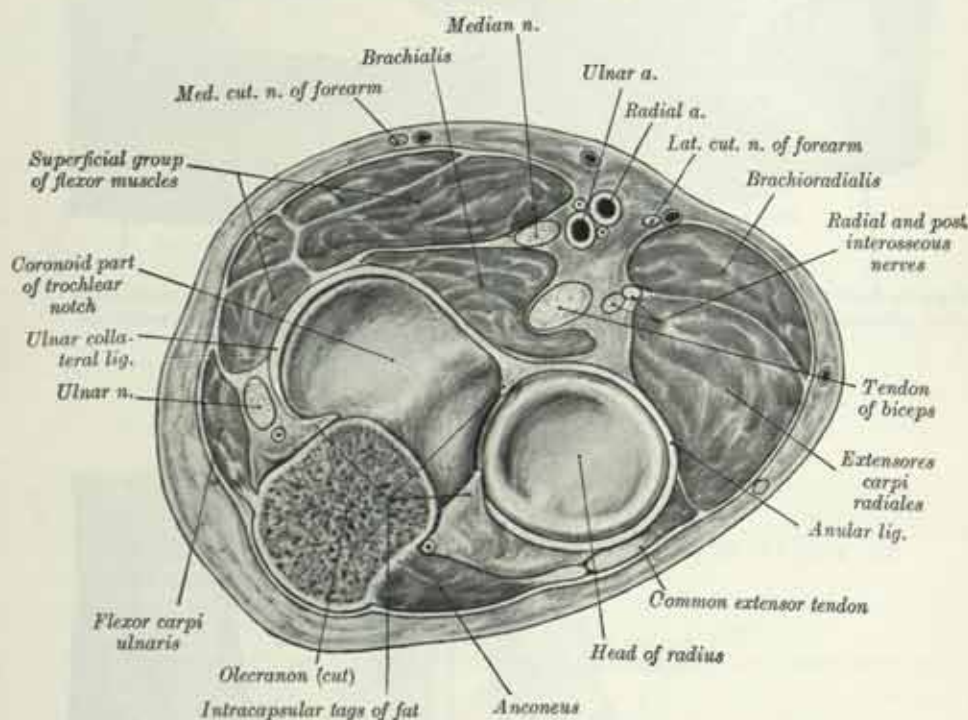


FIG. 512.—The left elbow joint. Viewed from the lateral side.



thinner intermediate portion. The *anterior portion* is attached above, by its apex, to the front part of the medial epicondyle of the humerus; and below, by its broad base, to a tubercle on the upper part of the medial margin of the coronoid process. The *posterior portion*, also of triangular form, is attached, above, to the lower and back part of the medial epicondyle; below, to the medial margin of the olecranon. Between these two bands a few intermediate fibres descend from the medial epicondyle to an *oblique band*—often feebly developed—which stretches between the olecranon and coronoid processes. This band converts the depression on the medial margin of the trochlear notch into a foramen, through which the intracapsular pad of fat is continuous with the extracapsular fat on the medial side of the joint. The ulnar collateral ligament is in relation with the triceps and flexor carpi ulnaris and the ulnar nerve. Along its anterior portion the origin of the flexor digitorum superficialis extends from the medial epicondyle of the humerus downwards and laterally to the medial border of the coronoid process of the ulna.

FIG. 513.—Transverse section of the right elbow joint, viewed from above, to show the relations of the joint.



The **radial collateral (lateral) ligament of the elbow joint** (fig. 512) is attached above to the lower part of the lateral epicondyle of the humerus, and below to the annular ligament, some of its most posterior fibres passing over that ligament to be inserted into the lateral margin of the ulna. It is intimately blended with the origins of the supinator and the extensor carpi radialis brevis.

The **muscles** in relation with the joint are, in front, the brachialis; behind, the triceps and anconeus; laterally, the supinator, and the common tendon of origin of the extensor muscles; medially, the common tendon of origin of the flexor muscles, and the flexor carpi ulnaris.

The **arteries** of supply are derived from the anastomotic network around the joint (p. 780).

The **nerves** of the joint are derived mainly from the musculo-cutaneous and radial nerves, but the ulnar, median and, sometimes, the interior interosseous nerve also contribute articular branches. The branch from the musculo-cutaneous arises from the nerve to the brachialis muscle and is distributed to the anterior part of the articular capsule. The articular branches of the radial nerve supply the posterior

and antero-lateral portions of the articular capsule and are derived both from the nerve to the anconeus and from the ulnar collateral branch to the medial head of the triceps muscle. The ulnar nerve supplies twigs to the ulnar collateral ligament as it lies behind the medial epicondyle.*

Movements.—The elbow is a hinge joint and its movements consist of flexion and extension, the ulna moving on the trochlea, and the head of the radius on the capitulum of the humerus; as the part of the capitulum which covers the inferior surface of the lower end of the humerus is smaller than the head of the radius, the posterior edge of the head of the radius can be felt projecting at the back of the joint when the forearm is fully extended. The movement of extension is limited by the tension of the fibrous capsule and muscles on the front of the joint; that of flexion chiefly by the apposition of the soft parts.

When the forearm is fully extended and the hand supinated, the upper arm and forearm are not in the same line; the forearm is directed somewhat laterally, and forms with the upper arm an angle of about 167° in the female and 173° in the male. This 'carrying angle' is caused partly by the medial edge of the trochlea of the humerus, which projects about 6 mm. below the lateral edge, and partly by the obliquity of the superior articular surface of the coronoid process, which is not set at right angles to the shaft of the ulna. The angles which the articular surfaces of the humerus and the ulna make with the long axes of the bones are approximately equal, and as a result the carrying angle disappears on full flexion of the forearm and the two bones come to lie in the same plane. When this movement is carried out with the arm by the side, the ulnar border of the little finger lies over the clavicle on account of the position of the resting humerus (p. 371). If the humerus is rotated laterally during the movement, the hand is carried upwards in front of the shoulder. The carrying angle is masked also in pronation of the extended forearm, and this has the effect of bringing the upper arm, the semipronated forearm and the hand into the same straight line. This arrangement increases the precision with which the hand, and any instrument or weapon held in the hand, can be controlled in full extension of the elbow or while the elbow is being extended.

The *accessory movements* of the elbow joint are very limited in range and are restricted to abduction and adduction of the ulna, and forward and backward movement of the head of the radius on the capitulum of the humerus. In the latter movement, the head of the radius is moved on the radial notch of the ulna also, the annular ligament being slewed backwards and forwards at the same time. The extent of this movement is greatest when the elbow joint is half-flexed.

III. THE RADIO-ULNAR JOINTS

The radius and the ulna are connected at their upper and lower extremities by synovial joints, termed the proximal and distal radio-ulnar joints. In addition, the shafts of the bones are connected by an interosseous membrane and a ligament, which together constitute a middle radio-ulnar union.

I. THE PROXIMAL RADIO-ULNAR JOINT

This articulation forms a pivot joint between the circumference of the head of the radius and the osseofibrous ring formed by the radial notch of the ulna and the annular ligament.

The **annular ligament** (figs. 512-515) is a strong band which encircles the head of the radius, and retains it in contact with the radial notch of the ulna. It forms about four-fifths of the osseofibrous ring and is attached to the anterior and posterior margins of the radial notch; a few of its lower fibres are continued round below the notch and form at this level a complete fibrous ring. Its upper border blends with the fibrous capsule and collateral ligaments of the elbow joint, while from its lower border a thin loose membrane passes to be attached to the neck of the radius. A few fibres extend from the inferior border of the radial notch to the neck

* E. Gardner, *Anat. Rec.*, 102, 1948.

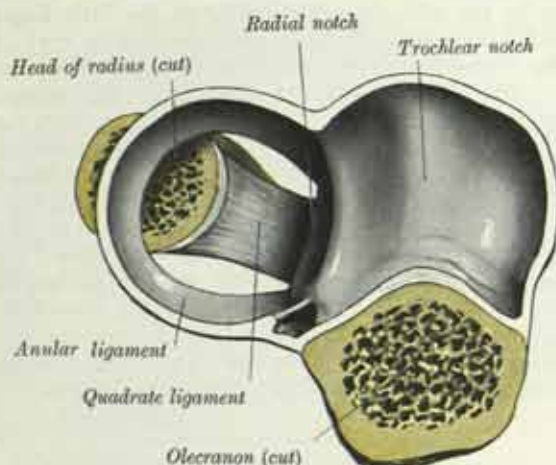
of the radius, covering the synovial membrane which closes the distal aspect of the joint. They constitute the *quadrato ligament*. The *superficial surface* of the anular ligament is strengthened by the radial collateral ligament of the elbow, and affords origin to part of the supinator. It is related posteriorly to the anconeus and the interosseous recurrent artery. On its *inner surface* the anular ligament is provided with a thin coating of cartilage where it comes into contact with the circumference of the head of the radius; its lower part is lined with synovial membrane which is reflected upwards on to the neck of the bone.

2. THE MIDDLE RADIO-ULNAR UNION

The shafts of the radius and ulna are connected by the oblique cord and the interosseous membrane of the forearm.

The **oblique cord** (fig. 515) is a small, flattened band, extending from the lateral side of the tuberosity of the ulna to the radius a little below the radial tuberosity. Its fibres run at right angles to those of the interosseous membrane. It is sometimes wanting.

FIG. 514.—The anular ligament of the left radius. Superior aspect. The head of the radius has been sawn off and the bone dislodged from the ligament.



The **interosseous membrane of the forearm** (fig. 515) is a broad and thin sheet, the fibres of which slant downwards and medially from the interosseous border of the radius to that of the ulna; the lower part of the membrane is attached to the posterior of the two lines into which the interosseous border of the radius divides. Two or three bands are occasionally found on the posterior surface of this membrane; their fibres descend obliquely from the ulna towards the radius, i.e. at right angles to the other fibres. The membrane is deficient above, commencing about 2 or 3 cm. below the tuberosity of the radius; is broader in the middle than at either end; and presents an oval aperture a little above its lower margin, for the passage of the anterior interosseous vessels to the back of the forearm. Between its upper border and the oblique cord there is a gap, through which the posterior interosseous vessels pass. The membrane connects the bones, and increases the extent of surface for the attachment of the deep muscles of the forearm. It also transmits to the ulna and thence to the humerus any force acting upwards through the hand and radius. It is tense when the hand is midway between the prone and supine positions and is relaxed a little in complete pronation and supination. *In front* the membrane is in relation, in its upper three-fourths, with the flexor pollicis longus on the radial side, with the flexor digitorum profundus on the ulnar side and between these muscles with the anterior interosseous vessels and nerve; in its lower one-fourth with the pronator quad-

ratus; *behind*, with the supinator, abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus, extensor indicis; and, near the wrist, with the anterior interosseous artery and posterior interosseous nerve.

FIG. 515.—The interosseous membrane of the forearm. Anterior aspect.

3. THE DISTAL RADIO-ULNAR JOINT

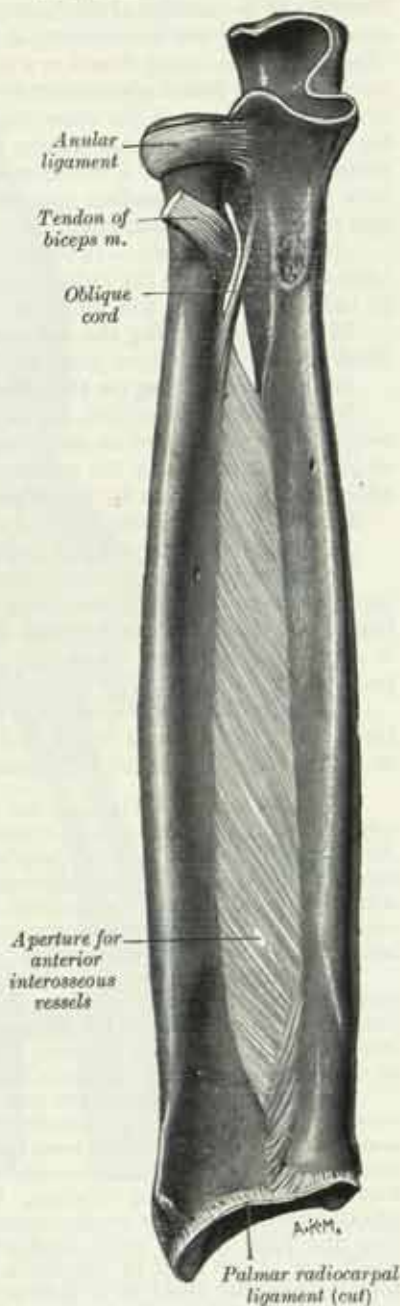
This is a pivot-joint formed between the head of the ulna and the ulnar notch of the lower end of the radius; the surfaces are enclosed in an articular capsule and held together by an articular disc.

The fibrous capsule is slightly thickened in front and behind; above, it is lax and lined with the synovial membrane, it projects upwards as a pouch (*recessus sacciformis*) in front of the lower part of the interosseous membrane.

The **articular disc*** (fig. 518), triangular in shape, binds the lower ends of the ulna and radius together. Its periphery is thicker than its centre, which is occasionally perforated. It is attached by its apex to a depression between the styloid process and the inferior surface of the head of the ulna; and by its base, which is thin, to the prominent edge which separates the ulnar notch from the carpal articular surface of the radius. Its margins are united to the ligaments of the wrist joint. Its *upper surface*, smooth and concave, articulates with the head of the ulna. Its *lower surface*, also smooth and concave, forms a part of the radiocarpal joint and articulates with the medial part of the lunate bone: when the hand is adducted, it articulates with the triquetral bone.

Movements.—The movements which take place at the radio-ulnar joints result in pronation and supination of the hand. In *pronation* the radius, carrying the hand with it, is carried obliquely across the front of the ulna, its upper end remaining lateral, and its lower end becoming medial, to that bone. In *supination* the movement is reversed and the radius lies lateral to and parallel with the ulna. When the movement is limited to the radio-ulnar joints, the hand can be turned through an angle of 140° – 150° , but, provided that the elbow-joint is extended, the apparent range can be increased to nearly 360° by rotation of the humerus accompanied by forward and backward movements of the shoulder girdle. The power of supination is greater than that of pronation, and thus all screw-driving instruments are made to be used in this movement.

The axis on which these movements take place is represented by a line drawn through the centre of the head of the radius above, and through the ulnar attach-



* This articular disc represents the modified inferior ligament of the distal radio-ulnar joint. See F. Wood Jones, *The Principles of Anatomy as seen in the Hand*, Second Edition. London, 1941.

ment of the articular disc below. The head of the radius rotates within the ring formed by the anular ligament and the radial notch of the ulna, while the lower end and the articular disc revolve on the head of the ulna. The lower end of the ulna is not stationary during these movements. It moves backwards and laterally during pronation, and forwards and medially during supination.* Although its range is limited, the occurrence of this movement means that during pronation and supination the axis of the movements, as just defined, becomes displaced laterally. In effect, the elbow being flexed to a right angle and the hand being allowed to move freely, the axis passes approximately through the middle finger, which has a smaller excursion than any of the other digits. If, however, slight resistance is imposed, for example by placing the supine hand on a flat surface, it will be found that in pronation the hand as a whole moves medially. Under these circumstances the little finger has the smallest excursion, the movement of the ulna is less, and the axis remains almost stationary.

Accessory movements.—In addition to the backward and forward movement of the head of the radius on the radial notch of the ulna (p. 493), the head of the ulna can be moved backwards and forwards on the ulnar notch of the radius.

Muscles producing the movements.—These muscles may be grouped as (a) those acting on the elbow joint, and (b) those acting on the radio-ulnar joints.

(a) **Muscles acting on the elbow joint :**

In **flexion**, the *brachialis*, *biceps* and *brachioradialis* are the prime movers, but, owing to the position of its attachments, the brachioradialis acts to best advantage when the forearm is in the midprone position. When resistance is encountered additional help is given by the *pronator teres* and the radial extensors of the wrist.

Extension is performed by the *triceps* and *anconeus*.

(b) **Muscles acting on the radio-ulnar joints :**

In **pronation**, the *pronator teres* and, to a slight extent, *pronator quadratus* (p. 632) are the prime movers, but, in order to overcome resistance, the *palmaris longus* and the *flexor carpi radialis* may be called into play, and the brachioradialis is capable of assisting from the position of full supination to the midprone position.

In **supination**, the *supinator* is the principal agent, but the *biceps* is a powerful factor when the elbow is flexed, and the brachioradialis is capable of participating in the movement from the fully prone to the midprone position.

Applied Anatomy.—Dislocations backwards and abduction dislocations are the commonest forms of dislocation at the elbow joint. Owing to the shapes of the bones, dislocation backwards is often complicated by fracture of the coronoid process; and, owing to the strength of the collateral ligaments, the medial epicondyle is frequently torn away in abduction dislocations. Dislocation of the elbow joint is common in children. In lesions of this joint it is often difficult to ascertain the exact nature of the injury except by X-ray examination.

The elbow joint is occasionally the seat of acute synovitis. The joint-cavity then becomes distended with fluid, the bulging showing itself principally around the olecranon, in consequence of the laxness of the articular capsule. Again, there is often some swelling, just above the head of the radius in the line of the humeroradial joint, or the whole elbow may assume a fusiform appearance.

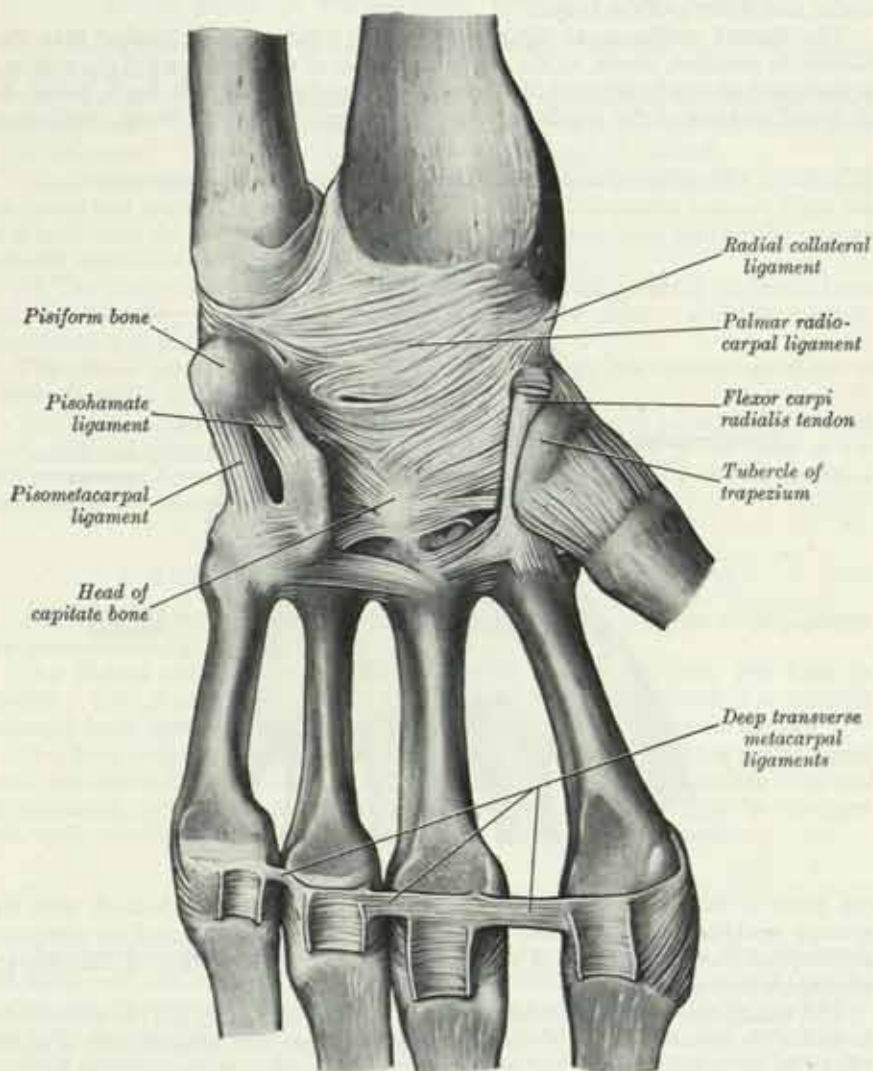
Dislocation of the head of the radius alone is a not uncommon accident, and occurs most frequently in young persons from falls on the hand when the forearm is extended and supinated, the head of the bone being displaced forward. It is attended by rupture of the anular ligament. Occasionally a peculiar injury, which is supposed to be a subluxation, occurs in young children. It is believed that the head of the radius is displaced downwards in the anular ligament, the upper border of which becomes folded over the head of the bone, between it and the capitulum of the humerus; the small size of the head of the radius in the child predisposes to this injury. The forearm becomes fixed in a position of semiflexion, midway between supination and pronation, and great pain is complained of when any attempt is made to move the joint.

* The movement of the ulna is difficult to analyse and to explain. It is often attributed to slight rotation of the humerus, lateral rotation carrying the flexed ulna laterally, and medial rotation carrying it medially. It may be, however, that the slight degree of incongruence of the trochlea and the trochlear notch provides a sufficient explanation.

IV. THE RADIOCARPAL OR WRIST JOINT

The radiocarpal or wrist joint (figs. 516-518) is a condyloid joint. The parts forming it are the distal end of the radius and lower surface of the articular disc, above; and the scaphoid, lunate, and triquetral bones, below. The *articular surface* of the radius and the lower surface of the articular disc form together a trans-

FIG. 516.—The ligaments of the left wrist and metacarpus. Palmar aspect.



versely elliptical, concave, surface—the *receiving cavity*. The proximal articular surfaces of the scaphoid, lunate, and triquetral bones form a smooth convex surface, which is received into the concavity. The line of the joint corresponds to a line, convex upwards, joining the styloid process of the radius to that of the ulna (Pl. XII).

The joint is surrounded by an **articular capsule**. The *synovial membrane* is usually distinct from that of the inferior radio-ulnar joint and from that of the intercarpal joints; the fibrous capsule is strengthened by the following ligaments:

Palmar radiocarpal.
Dorsal radiocarpal.
Radial collateral.

Palmar ulnocarpal.
Ulnar collateral.

The **palmar radiocarpal ligament** (fig. 516) is a broad membranous band,

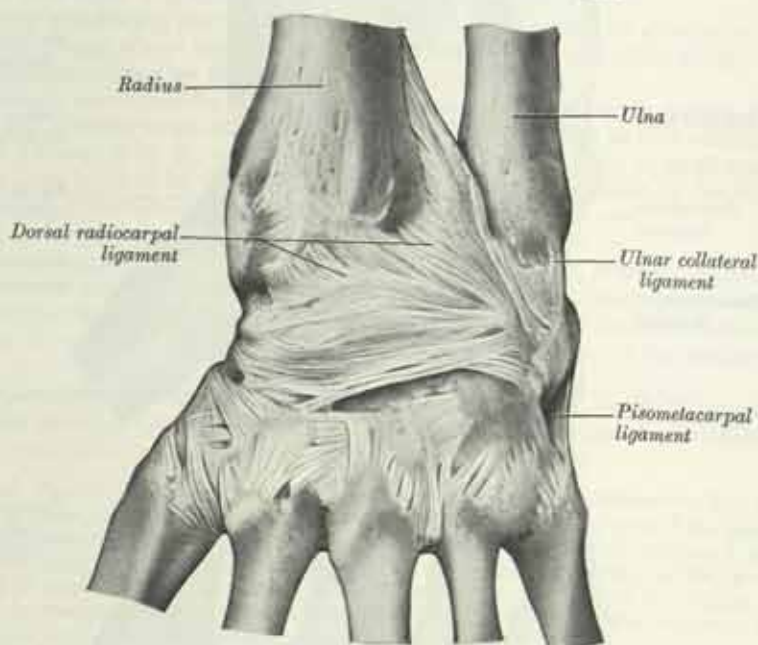
attached above to the anterior margin of the lower end of the radius and to its styloid process; its fibres pass downwards and medially to be attached to the anterior surfaces of the scaphoid, lunate and triquetral bones, some being continued to the capitate bone.

The **palmar ulnocarpal ligament** is a rounded fasciculus which runs from the base of the styloid process of the ulna and the anterior margin of the triangular articular disc of the distal radio-ulnar joint to the lunate and triquetral bones.

The palmar ligaments of the wrist are perforated by apertures for the passage of vessels and are in relation, in front, with the tendons of the flexor digitorum profundus and flexor pollicis longus.

The **dorsal radiocarpal ligament** (fig. 517), thinner and weaker than the anterior, is attached, above, to the posterior border of the distal end of the radius; its fibres are directed obliquely downwards and medially, and are fixed, below, to the dorsal surfaces of the scaphoid, lunate, and triquetral bones, being continuous

FIG. 517.—The ligaments of the left wrist. Dorsal aspect.



with those of the dorsal intercarpal ligaments. It is in relation, behind, with the extensor tendons of the wrist and fingers, their synovial sheaths and the posterior interosseous nerve; in front, it is blended with the articular disc of the inferior radio-ulnar articulation.

The **ulnar collateral ligament** of the wrist joint (figs. 516, 517) is attached to the end of the styloid process of the ulna; it divides into two fasciculi, one of which is fixed to the medial side of the triquetral bone, the other to the pisiform bone.

The **radial collateral ligament** of the wrist joint (figs. 516, 517) extends from the tip of the styloid process of the radius to the radial side of the scaphoid bone, some of its fibres being prolonged to the trapezium. It is in relation with the radial artery as it winds round the lateral side of the wrist separating the ligament from the tendons of the abductor pollicis longus and extensor pollicis brevis.

The *arteries* supplying the joint are the anterior interosseous, the anterior and posterior carpal branches of the radial and ulnar, the palmar and dorsal metacarpals, and some recurrent branches from the deep palmar arch. The *nerves* are derived from the anterior and posterior interosseous nerves.

Movements.—The movements which can be carried out at this joint cannot be dissociated from the corresponding movements which can be carried out at the intercarpal and particularly at the midcarpal joints. They will be considered after the joints of the carpus have been described (p. 500).

V. THE INTERCARPAL JOINTS

The intercarpal joints connect the carpal bones to one another and may be subdivided into : (1) joints between the bones of the proximal row of the carpus ; (2) joints between the bones of the distal row ; and (3) a somewhat complicated and extensive joint between the two rows, termed the midcarpal joint.

1. THE JOINTS OF THE PROXIMAL ROW OF CARPAL BONES

(a) The scaphoid, lunate and triquetral bones are connected by dorsal, palmar and interosseous ligaments.

The **dorsal** and **palmar ligaments** are placed transversely between the bones of the first row ; they connect the scaphoid bone to the lunate and the lunate bone to the triquetral. The palmar ligaments are weaker than the dorsal.

The **interosseous ligaments** (fig. 518) are two narrow bundles, one connecting the lunate and scaphoid bones, the other the lunate and triquetral bones. They are on a level with the proximal surfaces of these bones, and form part of the convex articular surface of the radiocarpal joint.

(b) The pisiform bone articulates with the palmar surface of the triquetral bone and the following are ligaments associated with the joint : articular capsule, pisohamate and pisometacarpal.

The *fibrous capsule* is thin, and surrounds the joint ; the *synovial membrane* is distinct from that of the other carpal joints.

The **pisohamate ligament** connects the pisiform to the hook of the hamate bone, and the **pisometacarpal ligament** joins the pisiform to the base of the fifth metacarpal bone (fig. 516). Both ligaments are continuous with the tendon of insertion of the flexor carpi ulnaris.

2. THE JOINTS OF THE DISTAL ROW OF CARPAL BONES

The bones of the distal row of the carpus are connected by the dorsal, palmar and interosseous ligaments.

The **dorsal** and **palmar ligaments** extend transversely from one bone to another ; one of each connects the trapezium and trapezoid bones, a second the trapezoid bone and the capitate, and a third the capitate bone and the hamate.

The three **interosseous ligaments** are much thicker than those of the proximal row ; one unites the capitate bone and the hamate, a second the capitate bone and the trapezoid, and a third the trapezium and trapezoid. The first is the strongest and rarely missing, while the second and third are frequently absent.

3. THE MIDCARPAL JOINT

The joint between the scaphoid, lunate and triquetral bones on the one hand, and the second row of carpal bones on the other is made up of two portions : on the medial side the head of the capitate bone and the hamate bone articulate with the concavity formed by the scaphoid, lunate and triquetral bones, and constitute a modified condyloid joint ; on the lateral side the trapezium and trapezoid articulate with the scaphoid bone and constitute a modified plane joint.

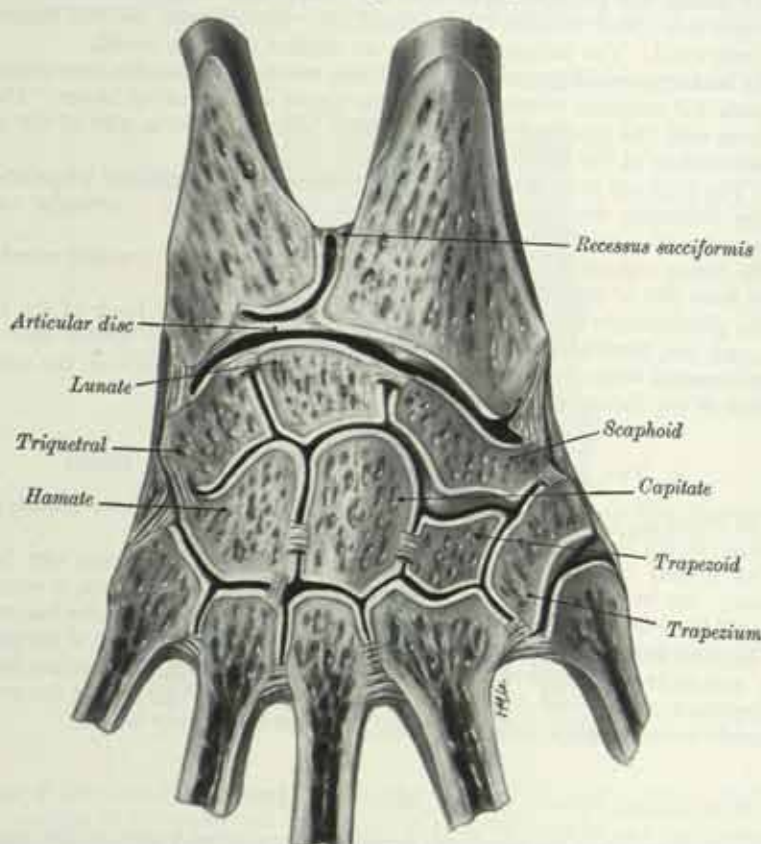
The ligaments are : dorsal, palmar, and two collateral.

The **dorsal** and **palmar ligaments** consist of short, irregular bundles passing between the bones of the first and second rows. On the palmar surface the fibres radiating from the head of the capitate bone to the surrounding bones are termed the *ligamentum carpi radiatum*.

The **collateral ligaments** are very short : the one is placed on the radial, the other on the ulnar side of the carpus : the former, the stronger and more distinct, connects the scaphoid bone and the trapezium, the latter the triquetral bone and the hamate ; they are continuous with the corresponding ligaments of the wrist joint. In addition to these ligaments, a slender, interosseous band sometimes connects the capitate and scaphoid bones, but it does not completely interrupt the midcarpal synovial cavity.

The **synovial membrane of the carpus** is very extensive (fig. 518), and bounds a cavity of very irregular shape. The proximal part of the cavity intervenes between the distal surfaces of the scaphoid, lunate and triquetral bones and the proximal surfaces of the bones of the second row. It sends two prolongations upwards—between the scaphoid and lunate bones, and between the lunate and triquetral bones—and three downwards between the four bones of the second row. The prolongation between the trapezium and the trapezoid, or that between the trapezoid and capitate bone, is, owing to the absence of the interosseous ligament, often continuous with the cavity of the carpometacarpal joints, sometimes of the second, third, fourth, and fifth metacarpal bones, sometimes of the second and third only. In the latter

FIG. 518.—A coronal section through the joints at the right wrist, showing the synovial cavities.



condition the joint between the hamate bone and the fourth and fifth metacarpal bones has a separate synovial membrane and is separated from the others (fig. 518) by the carpometacarpal interosseous ligament (p. 503). The synovial cavities of the carpometacarpal joints are prolonged for a short distance between the bases of the metacarpal bones. There is a separate synovial cavity between the pisiform and triquetral bones.

Movements.—The movements which occur at the radiocarpal and intercarpal joints are considered together, for the joints concerned form parts of the same mechanism and are acted on by the same muscle groups. The active movements which can be carried out are flexion, extension, adduction or ulnar deviation, abduction or radial deviation and circumduction.

When the wrist is *flexed*, both the radiocarpal and the midcarpal joints are implicated but the range of movement is greater at the latter. In *extension* the reverse is the case and most of the movement takes place at the radiocarpal joint (Plate XI). In consequence, the proximal surfaces extend further on the posterior than on the anterior surfaces of the lunate and scaphoid bones. These movements are limited

chiefly by the tension of the antagonistic muscles and, in this connexion, it may be noted that the range of flexion is perceptibly diminished when the fingers are flexed, owing to the increased tension of the extensor muscles. It is only when the joints are subjected to violence at the limits of flexion or extension that the dorsal or palmar ligaments, respectively, are fully stretched.

The range of *adduction* of the hand is considerably greater than the range of abduction, a fact which may be associated with the shortness of the styloid process of the ulna. In adduction, most of the movement occurs at the radiocarpal joint, and the lunate bone, which articulates both with the radius and with the articular disc when the hand is in line with the forearm (fig. 518), passes off the articular disc and comes to articulate only with the radius (Pl. XII, fig. 1).

In *abduction* the movement takes place almost entirely at the midcarpal joint and radiographs of the abducted hand show that the capitate bone rotates round an antero-posterior axis so that its head passes medially, and the hamate conforms to the movements of the capitate. As a result, the distance between the lunate bone and the apex of the wedge of the hamate is perceptibly increased (Pl. XII). The movements are limited by the tension of the antagonistic muscles and, when the extreme limits are reached, by the radial and ulnar collateral radiocarpal ligaments.*

Circumduction of the hand does not result from axial rotation but from the movements of flexion, adduction, extension and abduction carried out in that order or in the reverse order.

The **accessory movements** possible are obtained for the most part at the radiocarpal joint. They are relatively free and can be demonstrated more easily in flexion than in extension of the wrist. The carpus can be moved bodily backwards and forwards on the radius and articular disc and *it can be rotated axially to a considerable extent*. A little side to side movement is also possible.

It has recently been suggested † that, although the radiocarpal and the medial part of the midcarpal joint present the characters of condyloid joints, their mechanical equivalent is a 'link' joint, such as exists in its simplest form between the units of the chain of a bicycle. This type of joint is stable only when it is under tension and 'on centre', i.e. when the links are in line, and unless it is strengthened by the addition of a 'stop' mechanism, it buckles when subjected to a compressing force acting in its long axis, especially when it is 'off centre'. Certain advantages, however, are inherent in the 'link' joint. Since the range of movement at each of its constituent parts is appreciably less than the total range, the articular surfaces can be flatter than would be possible in a single joint giving the same total range of movement, and they are therefore better adapted to bearing pressure. Further, there is less tendency for the overlying tissues to be squeezed at the extremes of movement.

Muscles producing the movements :

In **flexion**, the *flexor carpi radialis*, *flexor carpi ulnaris* and *palmaris longus* are the principal agents, but the flexores digitorum, superficialis et profundus, the flexor pollicis longus and the abductor pollicis longus are capable of giving assistance.

In **extension**, the *extensores carpi radiales*, *longus et brevis*, and the *extensor carpi ulnaris* are the chief muscles concerned, but the extensor digitorum, extensor digiti minimi, extensor indicis and extensor pollicis longus are all potential helpers.

In **adduction**, the *flexor carpi ulnaris* acts in association with the *extensor carpi ulnaris*, and in **abduction** the *flexor carpi radialis* acts in association with the *extensores carpi radiales*, *longus et brevis*, and with the abductor pollicis longus and extensor pollicis brevis. As a result of these combinations of carpal flexors and extensors the movements of abduction and adduction can be carried out without the simultaneous occurrence of flexion and extension.

VIII. THE CARPOMETACARPAL JOINTS

1. THE CARPOMETACARPAL JOINT OF THE THUMB

This is a saddle-shaped joint between the base of the first metacarpal bone and the trapezium, and it enjoys great freedom of movement on account of the configuration of its articular surfaces. The joint is surrounded by a **fibrous capsule**, which is thick but loose, and passes from the circumference of the base of the metacarpal bone to the rough edge bounding the articular surface of the trapezium ; it is

* R. D. Wright, *J. Anat.*, Lond., 70, 1935.

† W. W. Gilford, R. H. Bolton and C. Lambrinudi, *Guy's Hospital Rep.*, 92, 1943.

thickest laterally and dorsally. The synovial membrane which lines the fibrous capsule is distinct from that of the other carpometacarpal joints (fig. 518).

The metacarpal bone of the thumb is connected to the trapezium by lateral, anterior and posterior ligaments in addition to the capsular ligament.

The lateral ligament is a relatively broad band, running from the lateral surface of the trapezium to the radial side of the base of the first metacarpal bone. The palmar and dorsal ligaments are oblique bands which converge on the ulnar side of the base of the metacarpal bone from the palmar and dorsal surfaces, respectively, of the trapezium. These two ligaments play an important part in connexion with the movements of the thumb.*

Movements.—In this joint the active movements that can be carried out are flexion, extension, abduction, adduction, rotation and circumduction. Owing to the set of the first metacarpal bone in the position of rest (p. 387), flexion and extension take place in a plane parallel to the plane of the palm, while abduction and adduction occur in a plane at right angles to the flexion-extension plane. Except in its early stages, flexion of the metacarpal bone is always associated with medial rotation and, conversely, medial rotation cannot be performed actively apart from flexion. The intimate association of these two movements is largely dependent upon the obliquity of the fibres of the dorsal ligament which, when taut, anchors the ulnar side of the base of the metacarpal bone whilst its radial side is free to move. Under these conditions contraction of the flexor brevis muscle alone will produce medial rotation combined with flexion.† This combined movement, together with abduction at the carpometacarpal joint, enables the tip of the thumb to be brought into contact with the palmar surfaces of the tips of the slightly flexed fingers, a movement which is termed *opposition*.

Full extension of the metacarpal bone of the thumb is associated with a slight amount of lateral rotation. This is attributable to the fact that the ulnar side of the base of the metacarpal bone becomes anchored by tension of the palmar ligament while the radial side is still free to move, and continued action of the extensors of the thumb produces lateral rotation in addition to further extension.

Accessory movements are limited to axial rotation in the position of rest, and distraction.

Muscles producing the movements :

In **flexion**, which cannot be dissociated from medial rotation, the *flexor pollicis brevis* and the *opponens pollicis* act as prime movers, and they are aided by the *flexor pollicis longus* when the other joints of the thumb are flexed.

In **extension**, the *abductor pollicis longus*, and the *extensores pollicis, brevis et longus*, are all actively concerned. In full extension the extensor pollicis longus, partly owing to the obliquity of its line of pull and partly owing to the disposition of the palmar ligament of the joint, rotates the thumb laterally and draws it dorsally, i.e. adducts it.

In **abduction**, the *abductor pollicis brevis* and the *abductor pollicis longus* are the prime movers. It should be noted that when the movement reaches its maximum the digit and its metacarpal bone are not in line, for the thumb is then abducted both at its metacarpophalangeal and at its carpometacarpal joints.

In **adduction**, the *adductor pollicis* is the sole muscle concerned, for the 1st palmar interosseous muscle acts only on the metacarpophalangeal joint.

In **opposition**, the abducted thumb is simultaneously flexed and rotated medially by the action of the *opponens pollicis* and the *flexor pollicis brevis*. The pressure which the opposed thumb can exercise on the tips of the fingers is increased by the reinforcing action of the adductor pollicis and the flexor pollicis longus.

In **circumduction**, the muscle groups come into action consecutively, the extensors, the abductors, the flexors and the adductors following one another in that order.

2. THE JOINTS OF THE SECOND, THIRD, FOURTH AND FIFTH METACARPAL BONES WITH THE CARPUS

The joints between the carpus and the second, third, fourth and fifth metacarpal bones are plane joints. The bones are united by **articular capsules**, strengthened by dorsal, palmar and interosseous ligaments.

* R. W. Haines, *J. Anat.*, Lond., 78, 1944.

† J. R. Napier, *J. Anat.*, Lond., 89, 1955.

The **dorsal ligaments**, which are the strongest and most distinct, connect the carpal and metacarpal bones on their dorsal surfaces. The second metacarpal bone receives two fasciculi, one each from the trapezium and trapezoid bones; the third metacarpal receives two, one each from the trapezoid and capitate bones; the fourth two, one each from the capitate and hamate bones; the fifth receives a single fasciculus from the hamate bone, and this is continuous with a similar ligament on the palmar surface, forming an incomplete fibrous capsule.

The **palmar ligaments** have a somewhat similar arrangement, with the exception of those of the third metacarpal bone, which are three in number: a lateral one from the trapezium, situated superficially to the sheath of the tendon of the flexor carpi radialis; an intermediate one from the capitate bone; and a medial one from the hamate bone.

The **interosseous ligaments** consist of short, thick fibres, and are limited to one part of the carpometacarpal articulation; they connect the contiguous distal margins of the capitate and hamate bones with the adjacent surfaces of the third and fourth metacarpal bones, and they may be united at their proximal ends.

The **synovial membrane** is often a continuation of that of the intercarpal joints. Occasionally, the joint between the hamate bone and the fourth and fifth metacarpal bones has a separate synovial membrane, and is then bounded on its lateral side by the more medial of the two interosseous ligaments just described, and by extensions from it to the palmar and dorsal parts of the capsule (fig. 518).

VII. THE INTERMETACARPAL JOINTS

The bases of the second, third, fourth and fifth metacarpal bones articulate with one another by small surfaces covered with cartilage, and are connected together by dorsal, palmar and interosseous ligaments.

The **dorsal** and **palmar ligaments** pass transversely from one bone to another on the dorsal and palmar surfaces. The **interosseous ligaments** connect the contiguous surfaces of the bones, just distal to their collateral articular facets.

The **synovial membrane** of these joints is continuous with that of the carpometacarpal articulations.

Movements.—The movements permitted in the carpometacarpal and intermetacarpal articulations of the fingers are limited to slight gliding of the articular surfaces upon each other, the extent of which varies in the different joints. They are really accessory movements of the first type (p. 457). The metacarpal bone of the little finger is the most movable, then that of the ring-finger; the metacarpal bones of the index and middle fingers are almost immovable.

The *accessory movements* are limited to spiral twisting of the metacarpus as a whole on the carpus.

VIII. THE METACARPOPHALANGEAL JOINTS

These articulations (figs. 519, 520) are of the condyloid variety and are formed by the reception of the rounded heads of the metacarpal bones into shallow cavities on the bases of the proximal phalanges. In each case the line of the joint lies nearly 2 cm. proximal to the proximal flexion crease of the digit. The metacarpophalangeal joint of the thumb is somewhat exceptional, for its movements of flexion and extension seldom exceed 60° and its side to side movements are very much restricted. Each joint has a palmar and two collateral ligaments.

The **palmar ligaments** are unusual in that they are thick, dense, fibro-cartilaginous structures, placed upon the palmar surfaces of the joints in the intervals between the collateral ligaments, to which they are connected; they are loosely united to the metacarpal bones, but are very firmly attached to the bases of the proximal phalanges. Their palmar surfaces are intimately blended with the deep transverse ligaments of the palm, and are grooved for the flexor tendons, the fibrous sheaths of which are connected to the sides of the grooves. Their deep surfaces form parts of the articular areas for the heads of the metacarpal bones.

The **deep transverse metacarpal ligaments** consist of three short, wide, flattened bands which connect the palmar ligaments of the second, third, fourth and

fifth metacarpophalangeal joints to one another (fig. 519). They are related, anteriorly, to the lumbrical muscles and the digital vessels and nerves and, posteriorly, to the interosseous muscles. Offsets from the digital slips of the central portion of the palmar aponeurosis join the palmar surface (p. 642). On both sides of the metacarpophalangeal joint of the middle and ring fingers (but only on the ulnar side of the index and on the radial side of the little finger) a slip passes from the dorsal surface of the ligament, deep to the tendon or tendons of the corresponding interosseous muscles, and joins the dorsal digital expansion (fig. 608).

FIG. 519.—The metacarpophalangeal and digital joints of the middle finger. Palmar aspect.

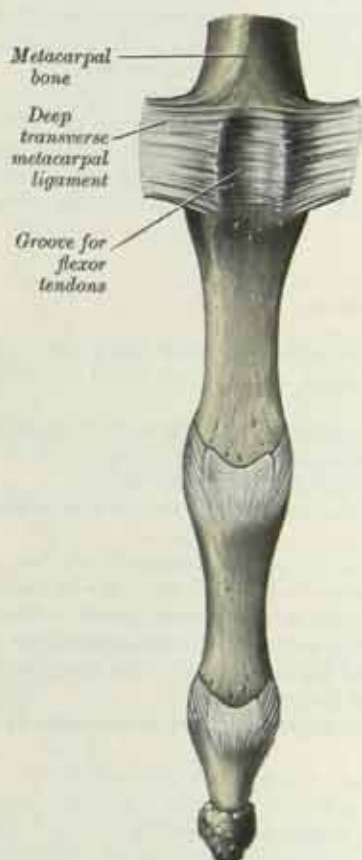


FIG. 520.—The metacarpophalangeal and digital joints of the right third finger. Medial aspect.



The **collateral ligaments** are strong, rounded cords, placed on the sides of the joints; each is attached to the posterior tubercle and adjacent depression on the side of the head of the metacarpal bone, and passes distally and forwards to reach the side of the base of the phalanx (fig. 520).

On the dorsal surfaces of these joints the fibrous capsule is thin and is separated from the extensor tendon by a bursa (fig. 606).

Movements.—The active movements which occur in these joints are flexion, extension, adduction, abduction, and circumduction.*

Flexion is freer than extension, and both movements are limited by the tension of the opposing muscles. Abduction and adduction are less free and cannot be performed actively when the fingers are flexed (*vide infra*).

The *accessory movements* comprise rotation (which in the case of the thumb may be considerable) and gliding of the phalanx on the head of the metacarpal bone

* Consult an article on "The Nerve-Supply of the Interphalangeal and Metacarpophalangeal Joints," by J. S. B. Stopford, *J. Anat., Lond.*, 56, 1921.

forwards, backwards and from side to side. In addition the articular surfaces can be separated by traction.

Muscles producing the movements :

In **flexion**, the *flexores digitorum superficialis et profundus* are assisted by the *lumbricals* and the *interossei* (p. 649) and, in the case of the little finger, by the *flexor digiti minimi*. In the thumb, the *flexores pollicis longus et brevis* are assisted by the first *palmar interosseous muscle*.

In **extension** of the middle and ring fingers at the metacarpophalangeal joints, the *extensor digitorum* is the only muscle concerned, but the *extensor indicis* and the *extensor digiti minimi* take part in extension of the index and little fingers, respectively. In the thumb the *extensores pollicis longus et brevis* are the only muscles concerned.

Adduction of the extended fingers is performed by the *palmar interossei*, but during flexion the long flexors of the fingers play the principal part. The slight degree of this movement in the thumb is attributable to the *adductor pollicis* and the first *palmar interosseous muscle*.

Abduction of the extended fingers is performed by the *dorsal interossei*, assisted by the long *extensors* except in the case of the middle finger. In the little finger the *abductor digiti minimi* is the principal agent, and the *abductor pollicis brevis* produces the slight movement possible in the thumb. When the fingers are in the flexed position, abduction cannot be performed actively, but, provided that the long flexors of the fingers are not in active contraction, it can easily be carried out passively. The inability to perform the movement actively in this position may be due to the fact that the dorsal *interossei* and the *abductor digiti minimi* are so shortened by flexion that they are unable to function, but the altered relation of the line of pull of the *interossei* to the axis of movement is probably the determining factor, for, whereas in extension of the digits the axis of side to side movements is antero-posterior, in flexion it is proximo-distal and the line of pull of the *interossei* is then nearly parallel to the axis; the inability is certainly not to be ascribed solely to tension of the collateral ligaments.

IX. THE INTERPHALANGEAL JOINTS (figs. 519, 520)

The interphalangeal or digital articulations are hinge joints, and each has a palmar and two collateral ligaments. The arrangement of these ligaments is similar to those in the metacarpophalangeal joints (p. 503). The extensor tendons obviate the need for dorsal ligaments. The proximal joint lies opposite the intermediate flexion crease of the digit, and the distal joint lies immediately distal to the distal crease.

Movements.—The only active movements which occur at the interphalangeal joints are flexion and extension; these movements are freer between the proximal and middle phalanges than between the middle and distal. The amount of flexion is very considerable, but extension is limited by tension of the digital flexors and, in violent movements, by the palmar ligaments.

The *accessory movements* comprise a limited range in each case of rotation, abduction, adduction and gliding forwards and backwards. They permit the fingers to adapt themselves to the shape of any object gripped in the hand, and they provide against the stresses and strains which occur during the ordinary use of the hand.

Muscles producing the movements :

In **flexion** of the proximal joint both the *flexor digitorum superficialis* and the *flexor digitorum profundus* are concerned; in the distal joint, the latter muscle is the sole agent. At the interphalangeal joint of the thumb the *flexor pollicis longus* is the only muscle available.

In **extension**, which takes place simultaneously at both joints, as in opening the closed fist, the *extensor digitorum* and the *extensor pollicis longus* are the chief muscles concerned.

Attention should be drawn at this point to the combined movements of flexion at the metacarpophalangeal joint and extension at the interphalangeal joints, which can be carried out simultaneously and are of such importance in the fine movements executed in writing, drawing, threading a needle (male method), etc. For many years it has been widely taught that the *lumbricals* and the *interossei* are not only

the active agents in producing flexion at the metacarpophalangeal joints, but are also the active agents in extending the interphalangeal joints through their attachments to the dorsal digital expansions (p. 634). It has recently been urged that, when the lumbricals and interossei flex the metacarpophalangeal joints, the balance between the tone of the digital flexors and extensors is altered in favour of the extensors, and that this factor alone is responsible for the extension of the interphalangeal joints.* However, both the lumbricals and interossei alone can extend these joints † (see p. 635).

THE JOINTS OF THE LOWER LIMB GIRDLE

I. THE SACRO-ILIAC JOINT (Plate XIII)

The sacro-iliac articulation is a synovial joint between the auricular surfaces of the sacrum and ilium. Although the joint is regarded as of the plane variety, the *articular surfaces* are not flat, but are marked by a number of irregular elevations and depressions. These irregularities fit into one another and provide a locking device which restricts movements to a minimum in order to ensure stability, for the sacro-iliac joint interrupts the line of weight transmission from the vertebral column to the lower limb. This mechanism permits the body-weight to be transmitted through the joint without causing tension of the ligaments. In the adult male a large number of short but strong bundles of fibres enter into the constitution of the sacro-iliac ligaments and, as a result, only a very small amount of anteroposterior rotatory movement is possible. In the female, after puberty, the range is appreciably greater and it is increased temporarily in the later months of pregnancy. In the elderly it is usual to find that the joint cavity is at least partly obliterated by the presence of fibrous or fibrocartilaginous adhesions. The ligaments of the joints are:

Ventral sacro-iliac.

Interosseous sacro-iliac.

Dorsal sacro-iliac.

The **ventral sacro-iliac ligament** (fig. 521) covers the anterior and inferior surfaces of the joint and consists of numerous thin bands. The superior fibres of the ligament connect the lateral part of the sacrum to the adjoining part of the iliac fossa; the inferior fibres are placed below the arcuate line, and unite the lateral parts of the three upper sacral vertebrae to the pre-auricular sulcus (p. 398) and adjacent part of the ilium.

The **interosseous sacro-iliac ligament** is very strong, and forms the chief bond of union between the two bones. It fills the irregular space immediately above and behind the joint cavity (figs. 524, 525) and is covered by the dorsal sacro-iliac ligament. It consists of bundles of short fibres which connect the iliac and sacral tuberosities.

The **dorsal sacro-iliac ligament** is oblique in direction; it connects the posterior superior iliac spine to the lateral crest of the sacrum. Its lower fibres are long and partly blended with the upper end of the sacro-tuberos ligament. Its upper fibres are short and pass ventrally as well as medially.

THE VERTEBROPELVIC LIGAMENTS

The ilium is connected to the fifth lumbar vertebra by the *iliolumbar ligament*, and the sacrum to the ischium by the *sacro-tuberos* and *sacrospinous ligaments*.

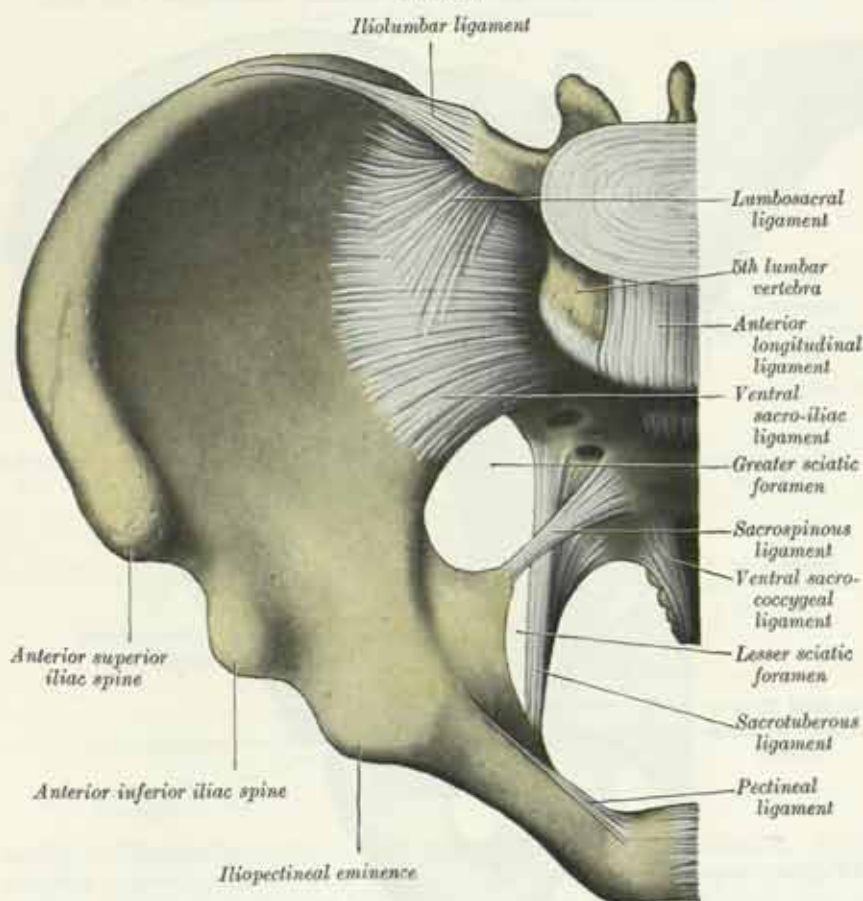
The **iliolumbar ligament** (fig. 521) is attached to the top and to the lower and front part of the transverse process of the fifth lumbar vertebra, and occasionally has an additional, weak attachment to the transverse process of the fourth. It radiates as it passes laterally and is attached by two main bands to the pelvis. The lower band, which is often termed the *lumbo-sacral ligament* (p. 245), runs from the inferior aspect of the fifth lumbar transverse process to the anterior part of the upper surface of the lateral part of the sacrum, blending with the ventral sacro-iliac ligament; the upper, which gives partial origin to the quadratus lumborum muscle, is attached to the crest of the ilium immediately in front of the sacro-iliac joint and is continuous above with the thoracolumbar fascia.

* F. Braithwaite, G. D. Channell, F. T. Moore and J. Whillis, *Guy's Hosp. Rep.*, 97, 1948.

† S. Sunderland, *Amer. J. Anat.*, 77, 1945.

The **sacrospinous ligament** (figs. 521, 522) is placed at the lower and posterior part of the pelvis. It is attached by a broad base to the posterior iliac spines (where it is partly blended with the dorsal sacro-iliac ligament), to the lower half of the lateral crest of the sacrum, and to the lateral margin of the lower part of the sacrum and upper part of the coccyx. Its fibres run obliquely downwards and laterally, and converge to form a thick, narrow band; this band widens out below and is fixed to the medial margin of the ischial tuberosity, and is continued along the ramus of the ischium under the name of the *falciform process*, the free concave edge of which gives attachment to the fascial sheath of the internal pudendal vessels and

FIG. 521.—The joints and ligaments of the right half of the pelvis. Viewed from in front.



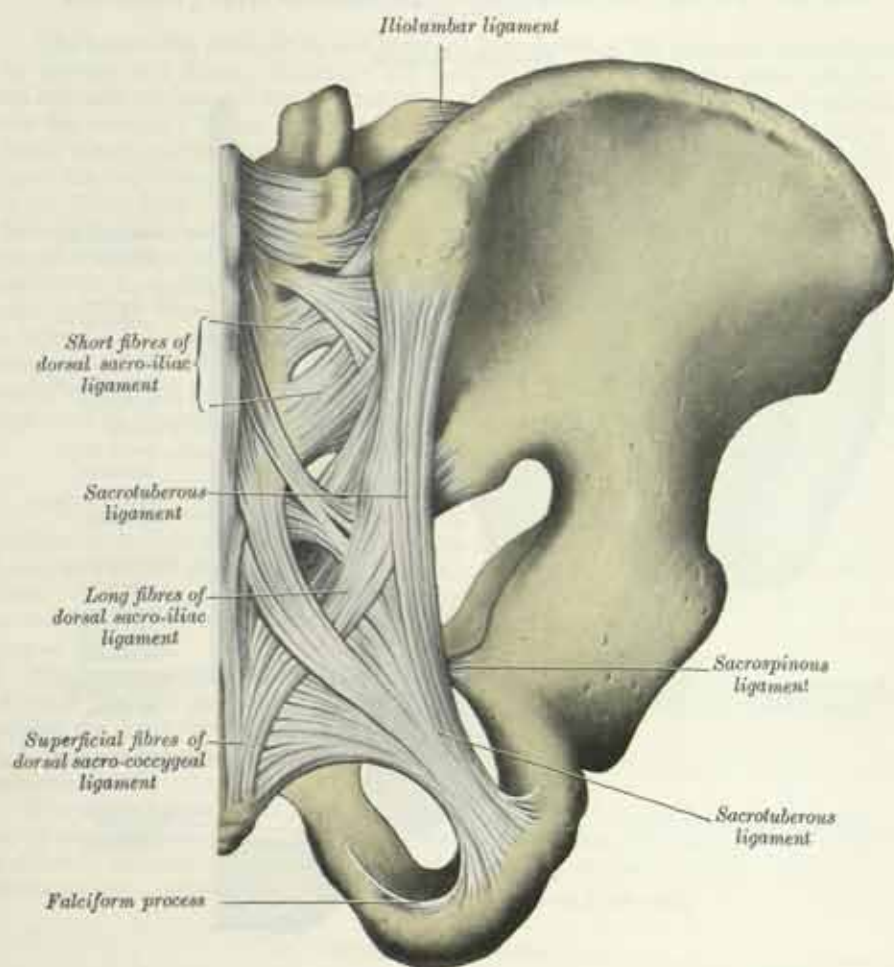
pudendal nerve (p. 606). On its posterior surface the ligament gives origin to the lowest fibres of the gluteus maximus, and some of the superficial fibres of its lower part are continued into the tendon of origin of the long head of the biceps femoris. The ligament is pierced by the coccygeal branches of the inferior gluteal artery, by the perforating cutaneous nerve and by minute filaments of the coccygeal plexus.

The **sacrospinous ligament** (fig. 521) is thin, and triangular in form; it is attached by its apex to the spine of the ischium, and, medially, by its broad base, to the lateral margins of the sacrum and coccyx, in front of the sacrotuberous ligament, with which its fibres are intermingled. It is in relation in front with the coccygeus muscle, to which it is closely connected, and of which it may represent a degenerated part.

These two ligaments convert the sciatic notches into foramina. The **greater sciatic foramen** is bounded, in front and above, by the greater sciatic notch; behind by the sacrotuberous ligament; and below by the sacrospinous ligament and the spine of the

ischium. It is partially filled up, in the recent state, by the piriformis muscle, which emerges from the pelvis through it. Above this muscle, the superior gluteal vessels and nerve pass out of the pelvis; and below it, the inferior gluteal vessels and nerve, the internal pudendal vessels and nerve, the sciatic and the posterior femoral cutaneous nerves, and the nerves to the obturator internus and quadratus femoris make their exit from the pelvis. The *lesser sciatic foramen* is bounded, in front, by the body of the ischium; above, by the body of the ischium and the sacrospinous ligament; behind, by the sacrotuberous ligament. It transmits the tendon of the obturator internus, the nerve to this muscle, and the internal pudendal vessels and nerve.

FIG. 522.—The joints and ligaments of the right half of the pelvis. Viewed from behind.



The sacrotuberous and, to a lesser extent, the sacrospinous ligaments would oppose any tendency of the lower part of the sacrum to tilt upwards under the downward thrust which is imparted to the upper end of the bone by the weight of the trunk (p. 511).

II. THE PUBIC SYMPHYSIS (figs. 483, 523)

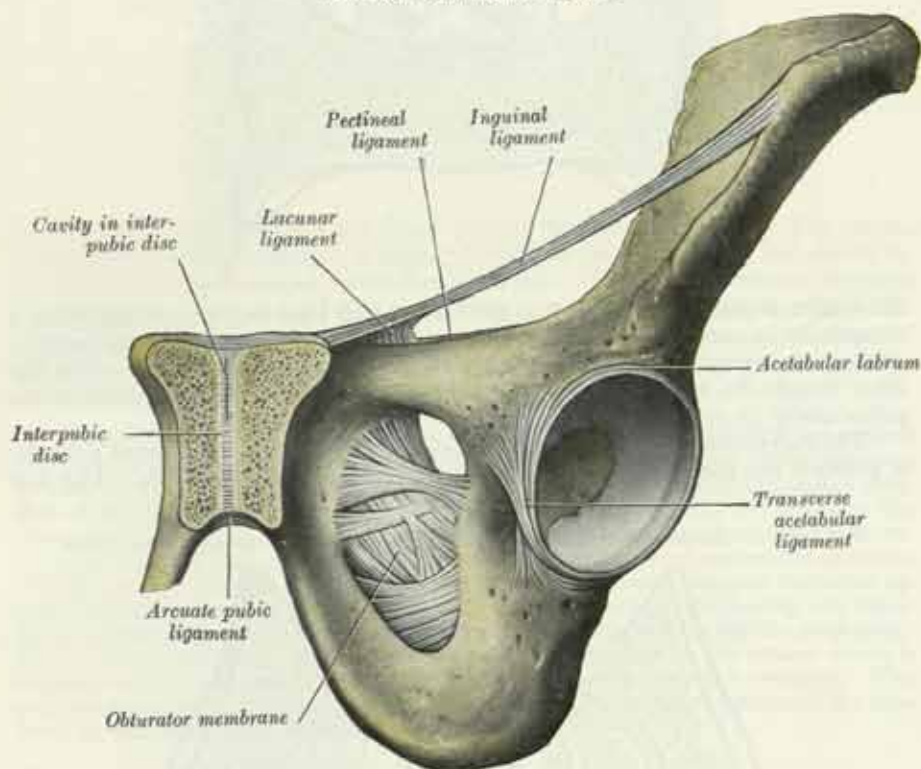
The pubic bones meet each other in the median plane, where they form a cartilaginous joint which receives the special name of the *pubic symphysis*. The two bones are connected by superior and arcuate pubic ligaments, and by an interpubic disc of fibrocartilage.

The **superior pubic ligament** connects the pubic bones superiorly, and extends as far as the pubic tubercles.

The **arcuate pubic ligament** is a thick, triangular arch of fibres, connecting the lower borders of the symphyseal surfaces of the two pubic bones, and forming the upper boundary of the pubic arch. Above, it is blended with the interpubic disc; laterally, it is attached to the inferior rami of the pubic bones; its base is free, and is separated from the free ventral border of the urogenital diaphragm by an opening through which the deep dorsal vein of the penis (or clitoris) enters the pelvis.

The **interpubic disc** connects the opposed surfaces of the pubic bones. Each of these surfaces is covered with a thin layer of hyaline cartilage firmly joined to the bone by a series of nipple-like processes which fit accurately into corresponding depressions on the osseous surface. These opposed surfaces are connected by a

FIG. 523.—An obliquely coronal section through the pubic symphysis. Viewed from its antero-inferior aspect.



lamina of fibrocartilage, which varies in thickness in different subjects. It often contains a cavity, probably formed by the softening and absorption of the fibrocartilage since it is rarely seen before the tenth year of life and is not lined with synovial membrane. This cavity is usually limited to the upper and back part of the joint; it occasionally reaches the front, and may extend the entire length of the cartilage. When present it may be demonstrated by making a coronal section of the symphysis pubis near its posterior surface (fig. 523). In front the disc is strengthened by several superimposed layers of fibres, which pass obliquely from one bone to the other, decussating and forming an interlacement with the fibres of the external oblique aponeuroses and the medial tendons of origin of the recti abdominis.

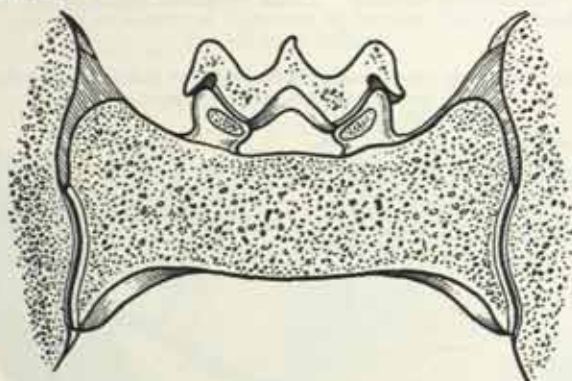
THE MECHANISM OF THE PELVIS

The pelvic girdle supports and protects the contained viscera and affords surfaces for the attachments of the muscles of the trunk and lower limb. Its most important mechanical function, however, is to transmit the weight of the head, trunk and upper limbs to the lower extremities.

It may be divided into two arches by a vertical plane passing through the acetabular cavities; the posterior of these arches is the one chiefly concerned in the

function of transmitting the weight of the trunk. Its essential parts are the upper three sacral vertebrae and two strong pillars of bone running from the sacro-iliac joints to the acetabular fossae (p. 402). The anterior of these arches is formed by the pubic bones and their superior rami. It connects the bases of the lateral pillars of the posterior arch and so acts as a tie-beam to prevent their separation and the consequent collapse of the arch. The sacrum forms the summit of the posterior arch;

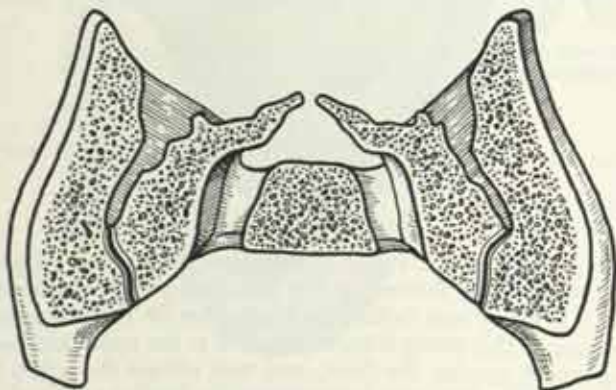
FIG. 524.—A coronal section through the sacro-iliac joints and the body of the first sacral vertebra. The sacrum is in its normal position with the body in the erect attitude.



the weight transmitted falls on it at the lumbosacral joint and, theoretically, has a component in each of two directions. One component of the force is expended in driving the sacrum downwards and backwards between the iliac bones, while the other thrusts the upper end of the sacrum downwards and forwards towards the pelvic cavity (p. 508).

The movements of the sacrum are regulated by its form. Viewed as a whole, it presents the shape of a wedge with its base upwards and forwards. The first

FIG. 525.—A coronal section passing through the middle of the sacro-iliac joints.



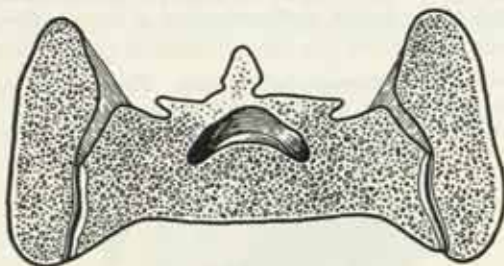
component of the force is therefore acting against the resistance of the wedge, and its tendency to separate the iliac bones is resisted by the sacro-iliac and iliolumbar ligaments and by the ligaments of the symphysis pubis.

If a series of coronal sections be made through the sacro-iliac joints, it will be found possible to divide the articular portion of the sacrum into three segments: anterior, middle, and posterior. In the *anterior segment* (fig. 524), which involves the first sacral vertebra, the articular surfaces show slight sinuosities and are almost parallel to one another. In the *middle segment* (fig. 525) the width between the dorsal margins of the sacral articular surfaces is greater than that between the ventral margins, and in the centre of each surface there is a concavity into which a corresponding convexity of the iliac articular surface fits. This forms an interlocking mechanism which prevents the strain of the body-weight from falling on the liga-

ments. In the *posterior segment* (fig. 526) the ventral width of the sacrum is greater than the dorsal, and the articular surfaces are only slightly concave.

Dislocation downwards and forwards of the sacrum by the second component of the force applied to it is prevented therefore by the middle segment, which interposes the resistance of its wedge-shape and that of the interlocking mechanism on its surfaces; a rotatory movement, however, is produced by which the anterior segment is tilted downwards and the posterior upwards: the axis of

FIG. 526.—A coronal section passing through the caudal parts of the sacro-iliac joints.



this rotation passes through the dorsal part of the middle segment. The movement of the anterior segment is slightly limited by its wedge-form, but chiefly by the dorsal and interosseous sacro-iliac ligaments; that of the posterior segment is checked to a slight extent by its wedge-form, but the chief limiting factors are the sacrotuberous and sacrospinous ligaments. In all these movements the effect of the sacro-iliac and iliolumbar ligaments and the ligaments of the symphysis pubis in resisting the separation of the iliac bones must be recognised.

Applied Anatomy.—During pregnancy the pelvic joints and ligaments are relaxed and capable therefore of more extensive movements. This relaxation of the ligaments renders the locking mechanism of the sacro-iliac joint less efficient and permits a rotation of the hip-bones to take place. This rotation has the effect of increasing the capacity of the pelvis. The less efficient the locking mechanism, the more the strain of weight-bearing falls on the ligaments, leading to the frequent occurrence of sacro-iliac strain after pregnancy. During involution the ligaments become tightened up again and the locking mechanism is restored, but, in some cases, the locking may occur in the position of rotation of the hip-bones which was adopted during the pregnancy. This so-called subluxation of the sacro-iliac joint causes pain by the tension which it imposes on the ligaments, and reduction by forcible manipulation is required. The common position found in this condition is believed to be backward rotation of the hip-bone on the sacrum; it is usually unilateral.

THE JOINTS OF THE LOWER LIMB

I. THE HIP JOINT

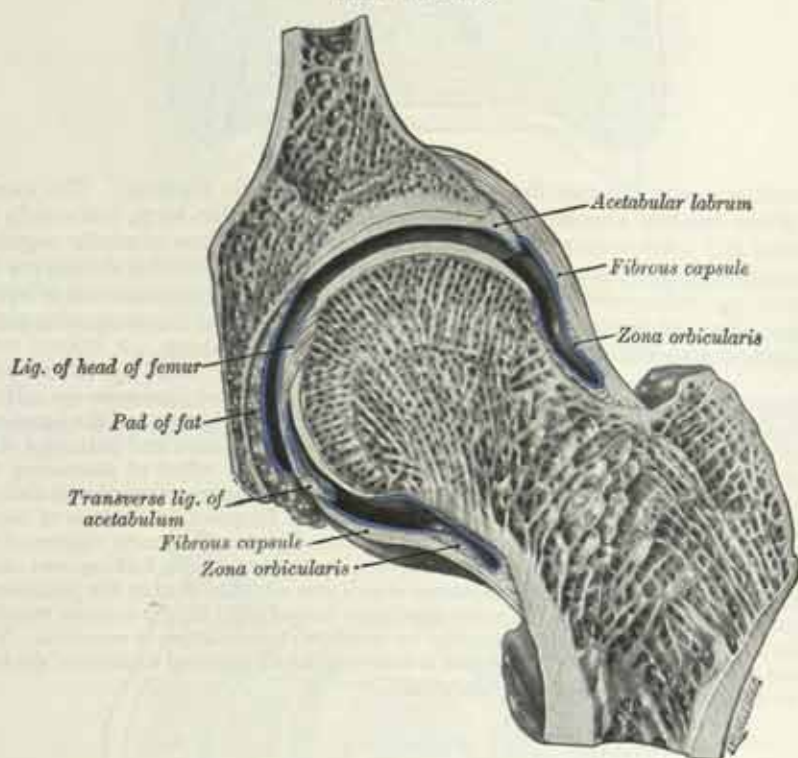
The hip joint is a cotyloid joint, formed by the reception of the head of the femur into the cup-shaped fossa of the acetabulum. It lies 1.2 cm. below the middle third of the inguinal ligament (Pl. XIII, fig. 1), to which the brim of the acetabulum is approximately parallel. The *articular surfaces* are reciprocally and regularly curved, but are not co-extensive. The head of the femur is completely covered with articular cartilage, except over the small, roughened pit to which the ligament of the head is attached. In front, the cartilage extends laterally to cover a small area on the adjoining part of the neck of the femur. The cartilage is thickest at the centre of the head and thinner towards its periphery. The articular surface of the acetabulum forms an incomplete ring, termed the lunate surface; broadest at its upper part where the pressure of the body-weight falls in the erect attitude and narrowest where it covers the pubic constituent. It is deficient below opposite the acetabular notch. It is covered with articular cartilage which is thickest where the lunate surface is broadest, but the floor of the acetabular fossa within this surface is devoid of articular cartilage and lodges a mass of fat covered with synovial membrane. The

depth of the acetabulum is appreciably increased by a fibrocartilaginous rim, termed the *acetabular labrum*. The ligaments of the joint are :

Articular capsule.	Pubofemoral.
Iliofemoral.	Ligament of the head of the femur.
Ischiofemoral.	The acetabular labrum.
Transverse acetabular.	

The **fibrous capsule** (figs. 529, 530) is strong and dense. Above, it is attached to the margin of the acetabulum, 5 or 6 mm. beyond the acetabular labrum ; in front, it is attached to the outer margin of the labrum, and, opposite the acetabular notch, to the transverse acetabular ligament and the edge of the obturator foramen. It surrounds the neck of the femur, and is attached in front to the trochanteric line ;

FIG. 527.—A section through the hip joint. The synovial membrane is shown in blue.



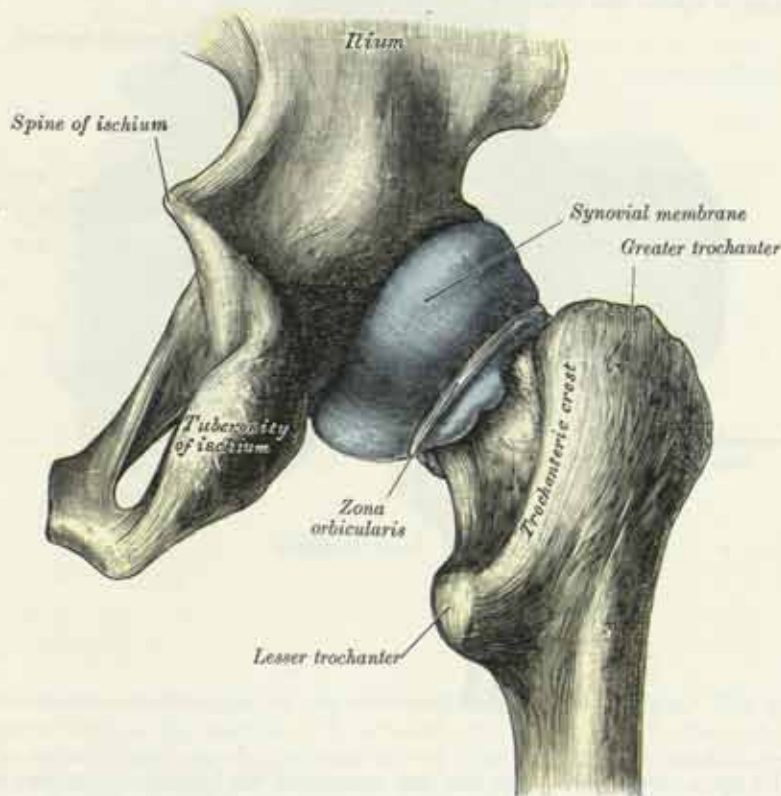
above, to the base of the neck ; behind, to the neck about 1 cm. above the trochanteric crest ; below, to the lower part of the neck close to the lesser trochanter (fig. 527). From its attachment to the front of the neck of the femur many of the fibres are reflected upwards along the neck as longitudinal bands, termed *retinacula*. The fibrous capsule is much thicker at the upper and fore part of the joint, where the greatest amount of resistance is required ; behind and below, it is thin and only loosely connected to the bone. It consists of two sets of fibres, circular and longitudinal. The circular fibres (*zona orbicularis*) are the deeper (fig. 527) and form a collar or ring round the neck of the femur (fig. 528). Although partially blended with the pubo- and ischio-femoral ligaments, these fibres have no direct attachment to bone. The longitudinal fibres are greatest in number at the upper and front part of the capsule, where they are reinforced by the *iliofemoral ligament*. The articular capsule is also strengthened by the *pubofemoral* and the *ischiofemoral ligaments*. The external surface of the capsule is rough, covered by numerous muscles, and separated in front from the *psoas major* and *iliacus* by a bursa.

The **synovial membrane** is very extensive. Commencing at the margin of the cartilaginous surface of the head of the femur, it covers the portion of the neck which is contained within the joint ; from the neck it is reflected on the internal

surface of the fibrous capsule, covers both surfaces of the acetabular labrum, ensheathes the ligament of the head of the femur, and covers the mass of fat contained in the acetabular fossa. It is very thin over the deep surface of that part of the iliofemoral ligament which is compressed against the head of the femur in the erect attitude and has been described as absent in this situation. The joint cavity communicates sometimes with the bursa of the psoas major tendon through a circular aperture which is situated between the pubofemoral ligament and the vertical band of the iliofemoral ligament.

The **iliofemoral ligament** (fig. 529), triangular in shape and of great strength, lies in front of the joint and is intimately connected with the capsule. Its apex is attached to the lower part of the anterior inferior iliac spine, its base to the trochanteric line of the femur. The medial and lateral parts of the ligament are strong bands, while the central part is relatively thin and weak; the medial band is vertical

FIG. 528.—The synovial cavity of the right hip joint (distended). Posterior aspect. (From a specimen prepared by J. C. B. Grant.)



in direction and is fixed to the lower part of the trochanteric line; the lateral band is oblique and is attached to the tubercle at the upper part of the same line. The iliofemoral ligament is frequently called the Y-shaped ligament, and its lateral band the **iliotrochanteric ligament**.

The **pubofemoral ligament** (fig. 529) is triangular in form with its base at the hip-bone, where it is attached to the iliopectineal eminence, the superior ramus of the os pubis, the obturator crest and obturator membrane; below, it blends with the capsule and with the deep surface of the medial band of the iliofemoral ligament.

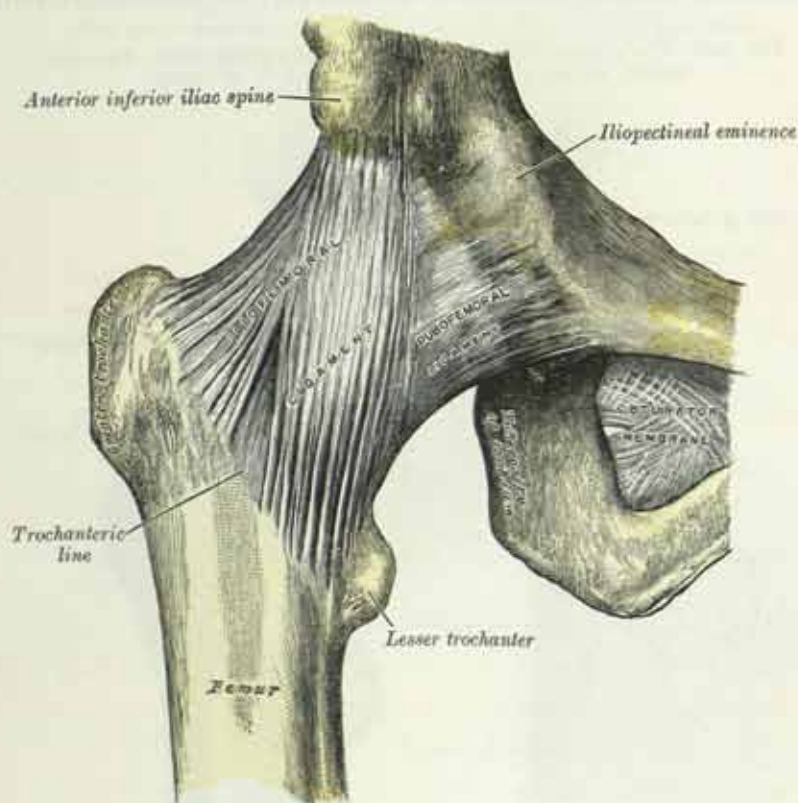
The **ischiofemoral ligament** (fig. 530) has a somewhat spiral disposition on the back of the joint. From its attachment to the ischium below and behind the acetabulum, it is directed upwards and laterally over the back of the neck of the femur. Some of its fibres are continuous with those of the zona orbicularis, others are fixed to the base of the greater trochanter.

The **ligament of the head of the femur** (fig. 531) is a triangular, somewhat flattened band implanted by its apex on the anterosuperior part of the pit on the head

of the femur; its base is attached by two bands, one into each side of the acetabular notch, and between these bony attachments it blends with the transverse ligament. It is ensheathed by synovial membrane, and varies greatly in strength in different subjects; occasionally only its synovial sheath exists, and in rare cases even this is absent. The ligament is made tense when the thigh is semiflexed and then adducted; it is relaxed when the limb is abducted.

The **acetabular labrum** (fig. 523) is a fibrocartilaginous rim attached to the margin of the acetabulum, the cavity of which it deepens. It bridges the acetabular notch as the *transverse ligament of the acetabulum*, and thus forms a complete circle. It is triangular on cross-section; the base is attached to the edge of the acetabulum,

FIG. 529.—The right hip joint. Anterior aspect.



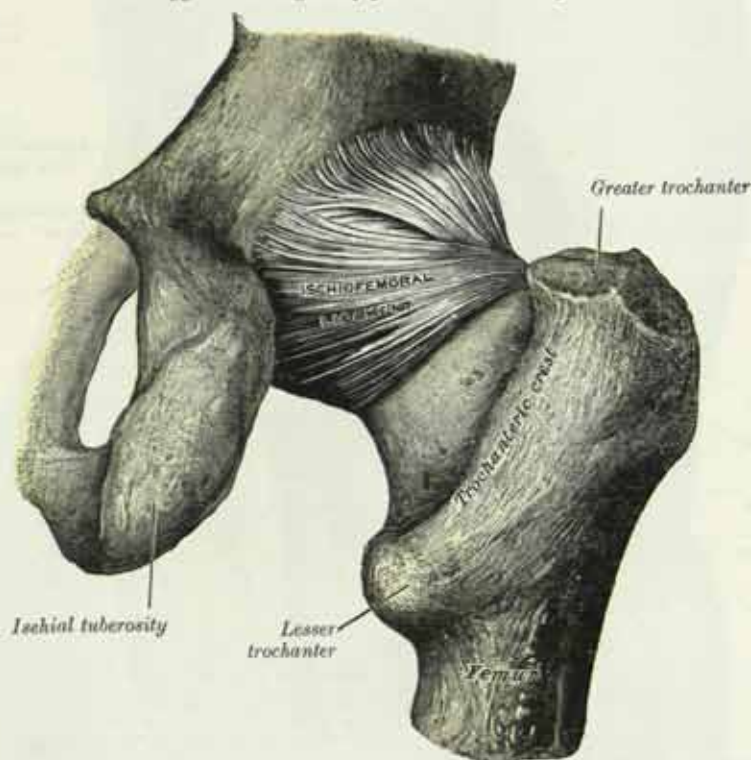
and the apex corresponds with the free margin of the labrum. The rim of the acetabular cavity is constricted by the free edge of the labrum, which is inturned and embraces the head of the femur closely so as to assist in holding it in its socket.

The **transverse ligament of the acetabulum** (fig. 523) is in reality a portion of the acetabular labrum, though differing from it in having no cartilage cells among its fibres. It consists of strong, flattened fibres, which cross the acetabular notch, and convert it into a foramen through which vessels and nerves enter the joint.

Relations of the hip joint.—The capsule is surrounded by muscles on all sides (fig. 532). *Anteriorly*, the lateral fibres of the pectineus intervene between the most medial part of the capsule and the femoral vein. Lateral to the pectineus the tendon of the *psoas major*, with the *iliacus* on its lateral side, runs downwards across the front of the capsule, partly separated from it by a bursa. In this situation the femoral artery is lying on the *psoas* tendon and the femoral nerve lies deeply in the groove between the tendon and the *iliacus*. More laterally the straight head of the *rectus femoris* crosses the joint and, under its lateral border, the deep layer of the *iliotibial tract* blends with the fibrous capsule.

Superiorly, the reflected head of the rectus femoris is in contact with the medial part of the capsule; the gluteus minimus covers the lateral part and is closely adherent to it. *Inferiorly*, the lateral fibres of the pectineus lie on the capsule as they incline backwards and, more posteriorly, the obturator externus crosses obliquely to gain the posterior aspect of the joint. *Posteriorly*, the lower part of the capsule is covered with the tendon of the obturator externus, which separates it from the quadratus femoris and is accompanied by the ascending branch of the medial circumflex femoral artery. Above that, the tendon of the obturator internus with the two gemelli is in intimate relation with the joint and intervenes between it and the sciatic nerve. The nerve to the quadratus femoris lies deep to the obturator

FIG. 530.—The right hip joint. Posterior aspect.



internus tendon and descends on the most medial part of the capsule. The uppermost part of the posterior surface of the articular capsule is crossed by the piriformis.

The *arteries* supplying the joint are derived from the obturator, medial circumflex femoral, and superior and inferior gluteal arteries.

The *nerves* are articular branches from the sacral plexus, the sciatic, obturator, and accessory obturator nerves, a branch from the nerve to the quadratus femoris, and a filament from the branch of the femoral nerve supplying the rectus femoris.

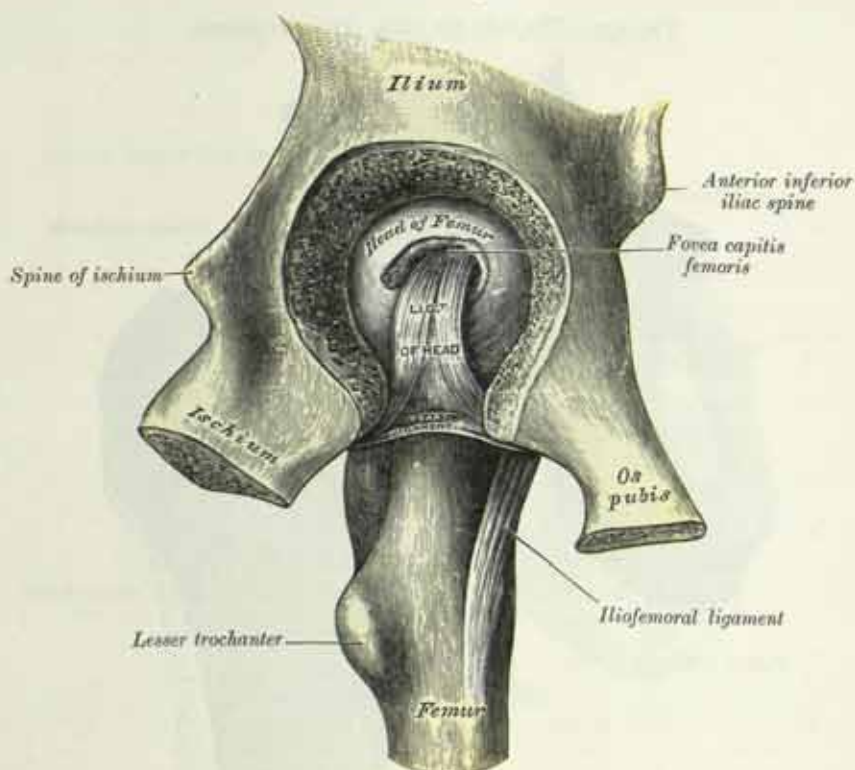
Movements.—The *active movements* of the hip joint are flexion, extension, adduction, abduction, circumduction, and rotation.

The length of the neck of the femur and its inclination to the body of the bone have the effect of converting the angular movements of flexion, extension, adduction, and abduction partially into rotatory movements in the joint. Thus when the thigh is flexed or extended, the head of the femur rotates within the acetabulum around a transverse axis. Rotation of the thigh takes place around a vertical axis which passes through the centre of the head of the femur and the intercondylar notch. The movements of abduction and adduction occur around an anteroposterior axis which passes through the centre of the head of the femur.

The hip joint presents a very striking contrast to the shoulder joint as regards the mechanical arrangements for its security and for the limitation of its movements. In the shoulder, as has been seen, the head of the humerus is not adapted in size to

the glenoid cavity, and its ordinary movements are restrained but little by the capsule. In the hip joint, on the contrary, the head of the femur is closely fitted to the acetabulum for an area extending over nearly half a sphere, and at the margin of the bony cup it is embraced still more closely by the acetabular labrum, so that the head of the femur is held in its place by that ligament even when the fibres of the capsule have been divided. The iliofemoral ligament is the strongest of all the ligaments in the body, and is put on the stretch by any attempt to extend the femur beyond a straight line with the trunk.

FIG. 531.—The left hip joint, opened by the removal of the floor of the acetabulum from within the pelvis.



Owing to the structure of the joint, no *accessory movements* are permitted with the exception of a very small degree of separation which can be effected by strong traction.

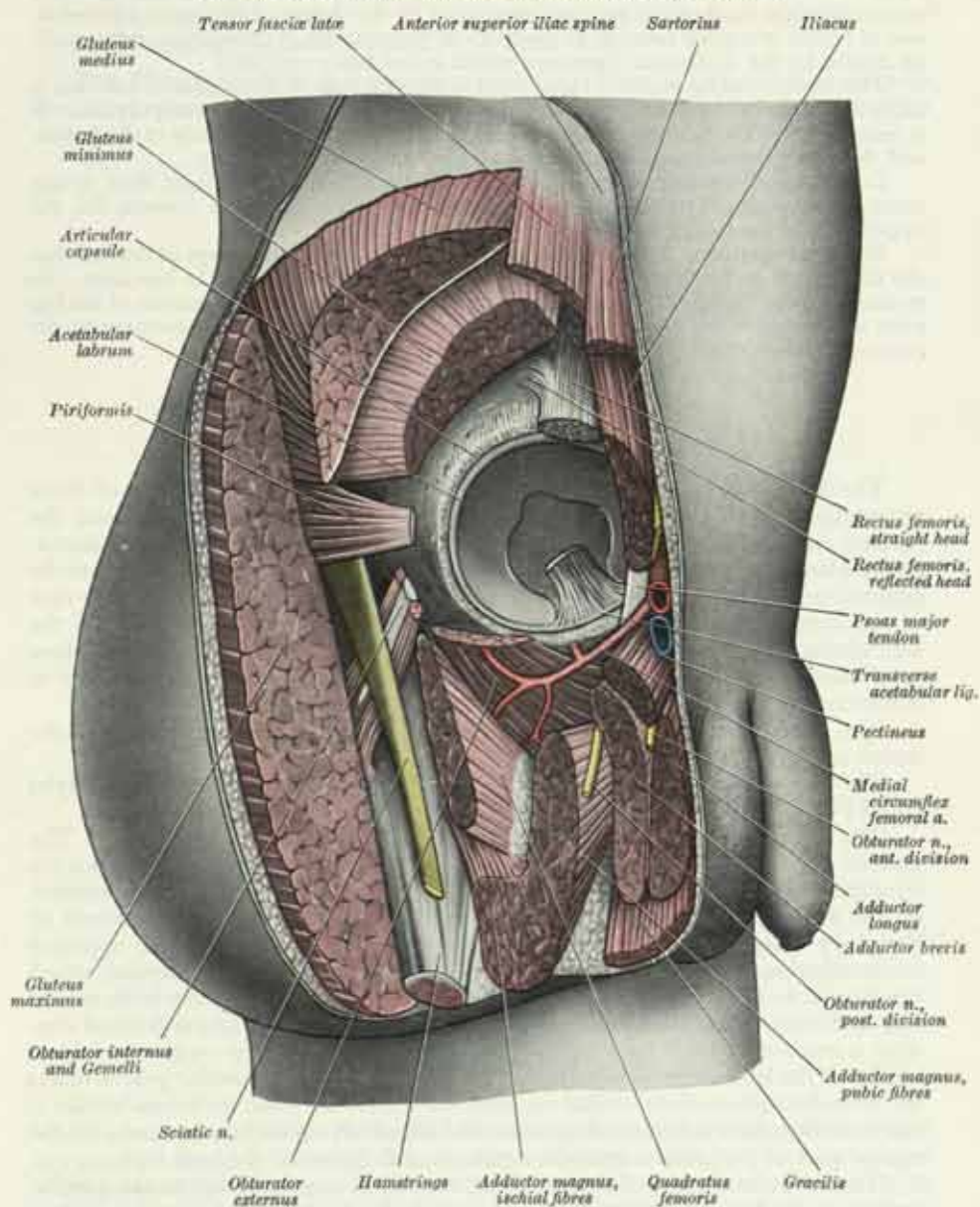
The principal **flexor** muscles are the *psoas major* and the *iliacus*, and they are assisted by the pectineus, rectus femoris and sartorius. The adductors participate in the movement especially in its early stages. When the knee is flexed, flexion of the hip is arrested by contact of the front of the thigh with the anterior abdominal wall. When extension of the knee is maintained, flexion of the hip joint is limited at an earlier stage by the tension of the hamstring muscles. It should be noted that contact of the front of the thigh with the abdominal wall implies supplementary movements at the sacro-iliac, lumbosacral and intervertebral joints, for it is not usually possible to obtain more than 100° of flexion at the joint itself.

The principal **extensor** muscle is the *gluteus maximus*, which is the true antagonist of the *psoas major* and *iliacus*. The hamstring muscles share in the production of the movement, when strong resistance is encountered. In the erect posture a vertical line passing through the centre of gravity of the trunk falls behind the line joining the centres of the femoral heads, and therefore the pelvis tends to fall backwards, but it is kept in position by the balanced tone of the flexor and extensor muscles. The iliofemoral ligaments prevent hyper-extension of the joint.

The principal **abductor** muscles are the *gluteus medius* (p. 665) and the *gluteus minimus*, and they are assisted by the tensor fasciæ latæ and the sartorius. Abduction is a free movement and it is limited by the tension of the adductor muscles, the

pubofemoral ligament and the medial band of the iliofemoral ligament. The principal **adductor** muscles are the *adductores longus, brevis et magnus*, assisted by the pectineus and the gracilis. Adduction is limited by contact with the opposite limb, but a wider range of movement can be obtained when the thigh is flexed.

FIG. 532.—A dissection to display the structures surrounding the right hip joint. The head of the femur has been disarticulated and removed.



Adduction of the flexed thigh is limited by the tension of the abductor muscles, the lateral band of the iliofemoral ligament and the ligament of the head of the femur.

Medial rotation is a relatively weak movement and no great force is required to prevent it. The principal muscles concerned are the *tensor fasciae latae* and the *anterior fibres of the glutei minimus et medius*. The movement is limited by the tension of the lateral rotator muscles, the ischiofemoral ligament and the posterior part of the fibrous capsule. **Lateral rotation** can be effected with considerable power. The principal muscles concerned are the *obturatores*, the *gemelli* and the

quadratus femoris, assisted by the *piriformis*, the *gluteus maximus*, the *sartorius* and the adductors. The movement is limited by the tension of the medial rotator muscles and by the lateral band of the iliofemoral ligament.

Applied Anatomy.—In dislocation of the hip, "the head of the thigh-bone may rest at any point around its socket" (Bryant); but whatever position it assumes ultimately, the primary displacement is generally downwards and medially, the capsule giving way at its weakest—that is, its lower and medial—part. The situation subsequently assumed by the head of the bone is determined by the degree of flexion or extension, and of lateral or medial rotation of the thigh at the moment of dislocation, influenced, no doubt, by the iliofemoral ligament, which is not easily ruptured.

The iliofemoral ligament is rarely torn in dislocations of the hip, and this fact is taken advantage of by the surgeon in reducing these dislocations by manipulation. It is made to act as the fulcrum to a lever, of which the long arm is the body of the femur, and the short arm the neck of the bone.

Congenital dislocation is met with more commonly in the hip joint than in any other articulation. The displacement usually takes place on to the *dorsum ilii*, the upper part of the rim of the acetabulum being deficient.

When manipulating the sacro-iliac joint the surgeon takes advantage of the fact that the iliofemoral and ischiofemoral ligaments are taut in extension of the hip joint. So strong are these ligaments that forcible attempts to produce hyperextension of the hip joint accompanied by forward pressure on the iliac crest result in movement at the sacro-iliac joint only.

II. THE KNEE JOINT (Plates XIV and XV)

The knee joint is a modified ginglymus or hinge joint. It consists of three articulations: two condyloid joints between the condyles of the femur and the menisci and condyles of the tibia; and a third between the patella and the femur, partly plane, but not completely so, since the articular surfaces are not mutually adapted to each other, so that the movement is not a simple gliding one. This view of the construction of the knee joint receives confirmation from a study of the articulation in some of the lower mammals, where, corresponding to these three subdivisions, three synovial cavities are found, either distinct from one another or connected by small communications.

The joint is partly subdivided by two menisci, which are placed between the femur and the tibia.

The line of the joint corresponds to the upper margins of the tibial condyles (Pl. XIV) and can be indicated by a line drawn round the limb at this level.

The *articular surfaces* (pp. 417, 422) are by no means congruent. The femoral condyles are convex from side to side and from before backwards, but the curvature is greatly accentuated posteriorly (fig. 440). Each tibial articular surface, on the other hand, though gently hollowed out centrally, is flattened around its periphery where it is covered with the corresponding meniscus. The opposing femorotibial surfaces are adapted to one another more closely by the menisci, which are shaped so as to render the inferior articular surface concave from both side to side and from before backwards. The articular surface of the lateral femoral condyle is marked in front by a faint groove (fig. 439) which rests on the peripheral border of the lateral meniscus in full extension of the joint. A similar groove marks the articular surface of the medial condyle, but it does not reach the lateral border of the condyle, where a narrow strip is marked off which comes into contact with the medial part of the patellar articular surface in full flexion of the knee.

The articular surface of the patella is adapted in a general way to the patellar surface of the femur. The vertical ridge which divides it into a larger, lateral part and a smaller, medial part fits into the corresponding groove on the femur, but the lateral and medial parts are only imperfectly congruent with the corresponding parts of the femur. The articular surface of the patella is divided still further by two faint, horizontal ridges which, with the vertical ridge, map out three pairs of facets.* On the medial side a second vertical ridge cuts off a narrow, elongated, semilunar strip from the medial border of the surface. This strip comes into contact with the

* In many patellæ only one horizontal ridge can be made out. It is better marked on the lateral area, and the upper and lateral facet differs from the others in being more deeply hollowed out.

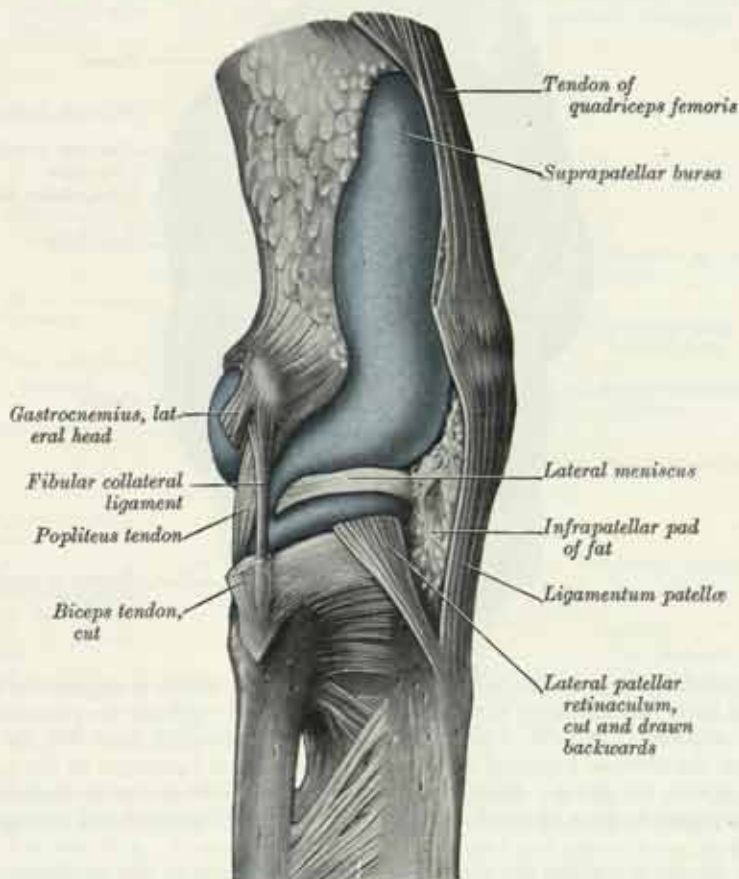
lateral part of the anterior end of the medial femoral condyle in full flexion, and in that position of the joint the uppermost lateral facet on the patella is in contact with the anterior part of the lateral condyle. As the knee is extended the middle facets of the patella come into contact with the lower half of the femoral patellar surface, and in full extension only the lowest patellar facets are in contact with the femur.

The ligaments of the joints are :

Capsule.	Tibial and fibular collaterals.
Ligamentum patellæ.	Anterior and posterior cruciate.
Oblique and arcuate popliteal.	Transverse.

The **fibrous capsule** is a very complicated structure, for in part it is deficient and in part it is replaced by strong expansions from the tendons of the muscles

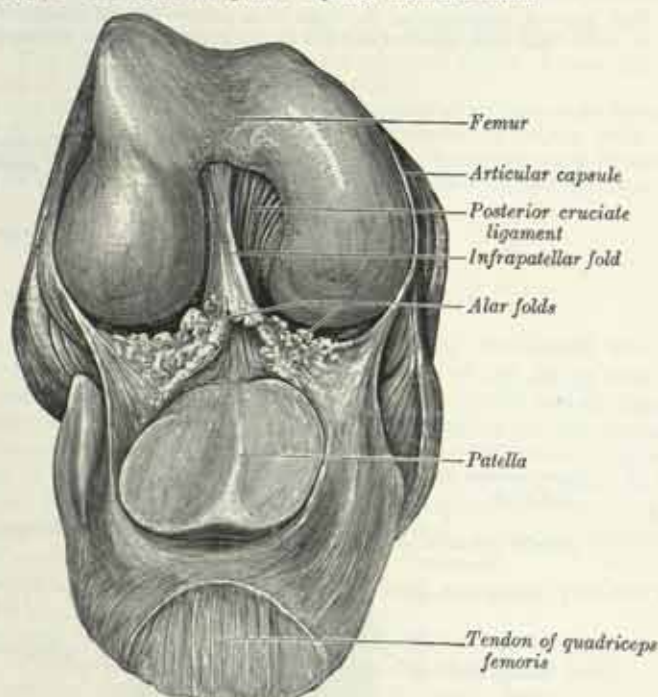
FIG. 533.—A dissection of the right knee joint. Lateral aspect. The joint cavity has been injected and the synovial membrane is coloured blue.



which surround the joint. Posteriorly, it consists of vertically running fibres which are attached above to the margins of the femoral condyles and the posterior margin of the intercondylar fossa, and below to the posterior margins of the tibial condyles and the posterior border of the intercondylar area. This part of the capsule is blended above on each side with the origin of the corresponding head of the gastrocnemius and centrally it is strengthened by the oblique popliteal ligament, with which its fibres interlace. On the medial side the fibres are attached to the medial surfaces of the femoral and tibial condyles beyond the articular margins. In this situation the fibrous capsule blends with the deep fibres of the tibial collateral ligament of the joint. On the lateral side the fibres are attached to the femur above the origin of the popliteus and they descend to the lateral condyle of the tibia covering the muscle. The fibular collateral ligament of the joint stands clear of the capsule and is separated from it by a little fat and the inferior lateral genicular vessels and nerve. Anteriorly,

the fibrous capsule is entirely wanting above the patella and over the patellar area. Elsewhere it blends indistinguishably with expansions from the vastus medialis and vastus lateralis. The expansions are attached to the margins of the patella and ligamentum patellæ and extend backwards on each side as far as the corresponding collateral ligament and downwards to the condyles of the tibia. They form the *medial* and *lateral patellar retinacula*, and the latter is further strengthened by the iliotibial tract, which partially covers and blends with the expansion from the vastus lateralis. Above the patella the deficiency of the fibrous capsule allows the suprapatellar bursa (p. 526) to communicate freely with the cavity of the joint. Posteriorly, the attachment of the fibrous capsule to the posterior surface of the lateral tibial condyle is interrupted, and in this situation the popliteus emerges from within

FIG. 534.—The right knee joint. Opened from the front.



the capsule (fig. 537). The oblique popliteal ligament, which is augmented by fibres derived from the tendon of the semimembranosus, strengthens the posterior aspect of the capsule. Laterally, a prolongation from the iliotibial tract fills the interval between the oblique popliteal and the fibular collateral ligaments of the joint, and partly covers the latter. Medially, expansions from the sartorius and semimembranosus muscle pass upwards to the tibial collateral ligament and strengthen the capsule.

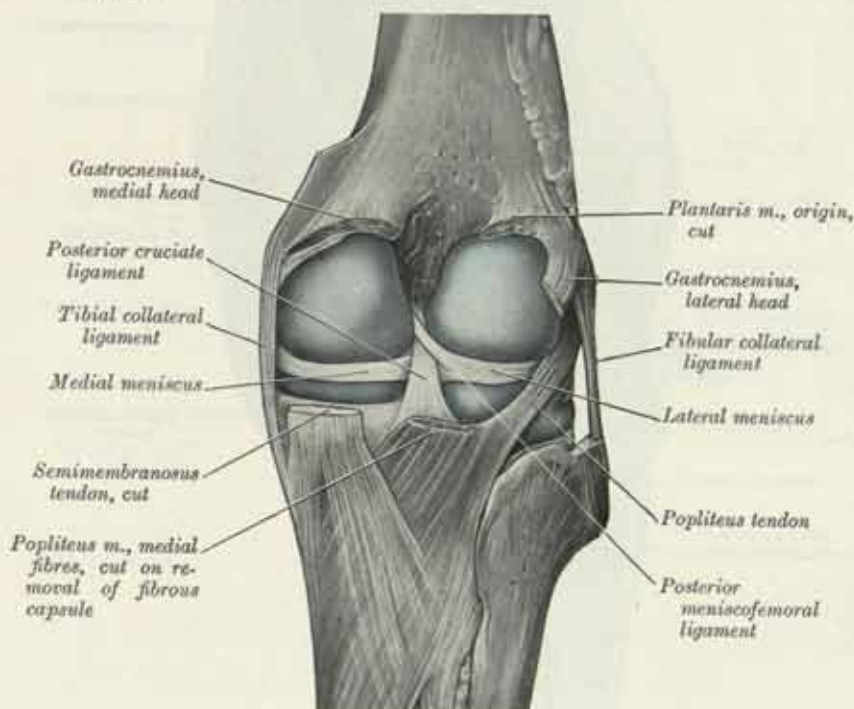
On its deep surface the fibrous capsule is attached to the periphery of each meniscus and connects it to the adjacent margin of the head of the tibia. This connexion is often termed the *coronary ligament*.

The **synovial membrane** of the knee joint is the most extensive in the body. Commencing at the upper border of the patella, it forms a large pouch under cover of the quadriceps femoris on the lower part of the front of the femur (figs. 533, 541), and usually communicates with a bursa interposed between the tendon and the front of the bone. The pouch between the quadriceps and front of the femur is upheld, during the movements of the knee, by a small muscle, named the articularis genu, which is inserted into it. On either side of the patella, the synovial membrane extends beneath the aponeuroses of the vasti, and more especially beneath that of the vastus medialis. Below the patella it is separated from the ligamentum patellæ by a considerable quantity of fat, known as the *infrapatellar pad*. Opposite the medial and lateral borders of the lower part of the articular surface of the patella, the synovial membrane covering the infrapatellar pad is projected into the interior of the joint in

the form of two fringe-like folds termed the *alar folds*; behind, these folds converge and are continued as a single band, named the *infrapatellar fold*, to the front of the intercondylar fossa of the femur (fig. 534). By its position, attachments and structure the infrapatellar fold may be identified as a vestige of the inferior boundary of the originally separate femoropatellar joint (p. 518).

At the sides of the joint the synovial membrane passes downwards from the femur, lining the fibrous capsule as far as its attachment to the menisci, the free surfaces of which possess no covering of synovial membrane. At the back part of the lateral meniscus the synovial membrane forms a cul-de-sac, the *sub-popliteal recess*, between the groove on the surface of the meniscus and the tendon of the popliteus (fig. 535). The relation of the synovial membrane to the cruciate ligaments of the knee joint is described on p. 524.

FIG. 535.—A dissection of the right knee joint from behind. The fibrous capsule has been removed, exposing the unopened synovial membrane, which is coloured blue. The cavity of the joint had been partially distended by injection.



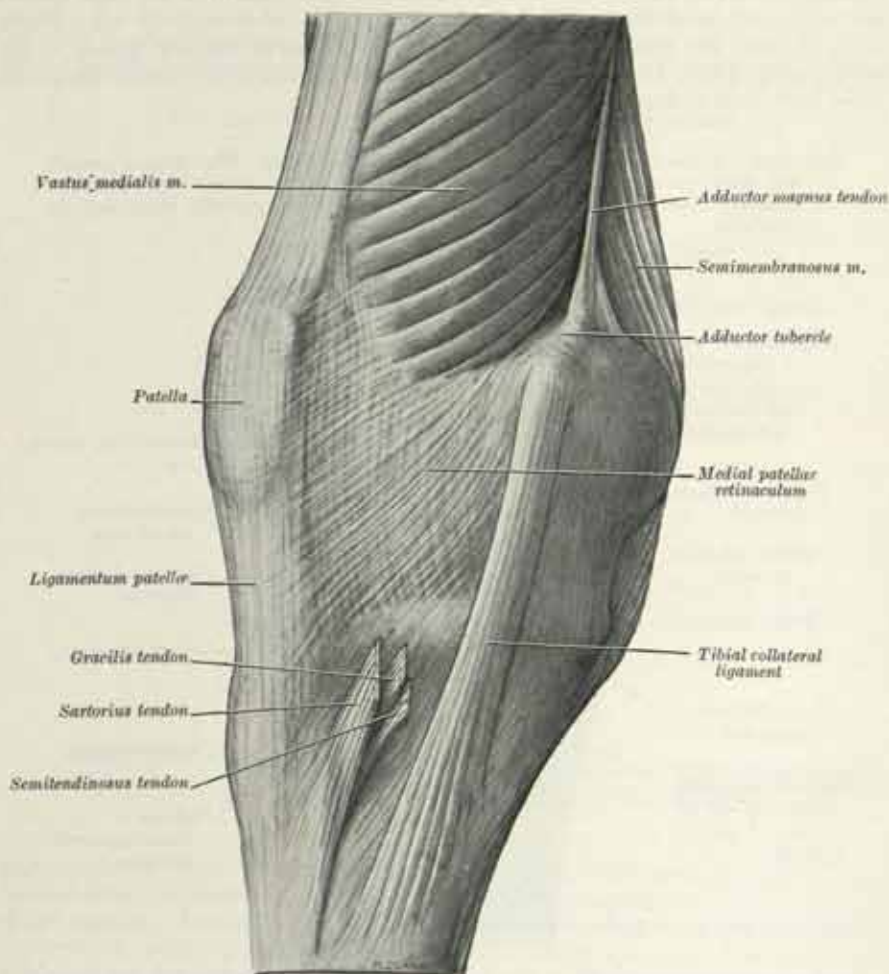
The **ligamentum patellæ** (fig. 536) is the central portion of the common tendon of the quadriceps femoris, which is continued from the patella to the tuberosity of the tibia. It is a strong, flat, ligamentous band, about 8 cm. in length, attached, above, to the apex and adjoining margins and to the rough depression on the lowest part of the posterior surface of the patella; and below, to the upper part of the tuberosity of the tibia; its superficial fibres are continuous over the front of the patella with those of the tendon of the quadriceps femoris. The medial and lateral portions of the tendon of the quadriceps pass down, one on each side of the patella, to be inserted into the upper extremity of the tibia, one on each side of the tuberosity; these portions merge into the fibrous capsule, as stated above, forming the medial and lateral patellar retinacula. The posterior surface of the ligamentum patellæ is separated from the synovial membrane by a large infrapatellar pad of fat, and from the tibia by a bursa (fig. 541).

The **oblique popliteal ligament** (fig. 537) is a broad, flat, fibrous band, formed of fasciculi separated from one another by apertures for the passage of vessels and nerves. It is attached, above, to the lateral part of the intercondylar line and to the lateral condyle of the femur, and below, it gradually blends with the fibrous capsule, which constitutes its principal connexion. It consists of a strong fasciculus

which is derived from the tendon of the semimembranosus close to its insertion into the tibia, and it becomes partially blended with the capsule as it passes upwards and laterally across its posterior part. The oblique popliteal ligament forms part of the floor of the popliteal fossa, and the popliteal artery rests upon it.

The **arcuate popliteal ligament** (fig. 537) is an arched bundle of fibres which varies somewhat in strength and appearance. It is attached to the lateral

FIG. 536.—The right knee joint. Anteromedial aspect.



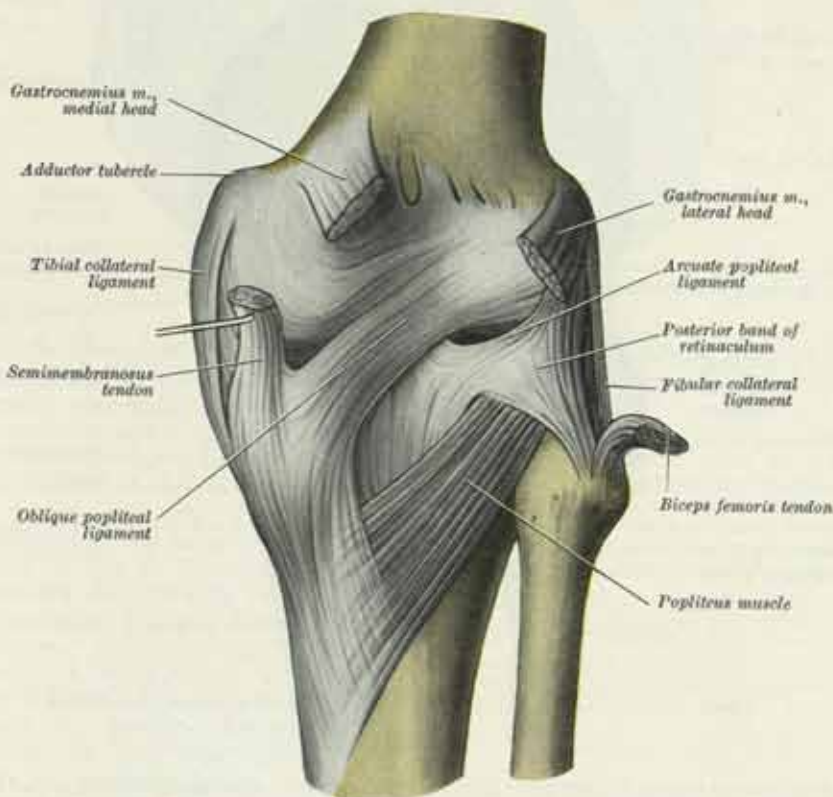
condyle of the femur and passes downwards to fuse with the fibrous capsule. Two bands, an anterior and a posterior, converge from the upper and lower extremities of the arcuate ligament; they unite below to form the *retinaculum* of the ligament, which is fixed to the apex of the head of the fibula. The anterior band of this retinaculum is sometimes described as the *short lateral ligament* and the tendon of the popliteus emerges from under cover of the posterior band (fig. 537). In fig. 537 the oblique upper border of the arcuate ligament shows an upward concavity, but in many cases it is straight and blended with the capsule. Some anatomists describe the ligament as a Λ -shaped band, consisting of femoro-tibial and femoro-fibular parts, which straddle the emerging tendon of the popliteus muscle.

The **tibial collateral ligament** (figs. 536, 542) is a broad, flat band, situated nearer to the back than to the front of the joint. It is attached, above, to the medial epicondyle of the femur immediately below the adductor tubercle; below, to the medial condyle and medial surface of the shaft of the tibia. The fibres of the posterior part of the ligament are short and incline backwards as they descend; they blend with the fibrous capsule and are inserted into the tibia above the groove for the semimembranosus. The anterior part of the ligament, about 10 cm. long,

is easily distinguished from the fibrous capsule which lies deep to it. It inclines forwards as it descends and is inserted into the medial margin and the posterior part of the medial surface of the shaft of the tibia (fig. 449). It is crossed, at its lower part, by the tendons of the sartorius, gracilis, and semitendinosus, a bursa being interposed. Its deep surface covers the inferior medial genicular vessels and nerve, and the anterior portion of the tendon of the semimembranosus, with which it is connected by a few fibres; *its upper part is adherent to the periphery of the medial meniscus*. One or more small bursæ may occur deep to the ligament and one of these may separate its anterior part from the medial meniscus.*

The **fibular collateral ligament** (fig. 538) is a strong, rounded cord, attached, above, to the lateral epicondyle of the femur, immediately above the groove for the tendon of the popliteus; below, to the lateral side of the head of the fibula, in front

FIG. 537.—The right knee joint. Posterior aspect.



of the apex. The greater part of it is hidden by the tendon of the biceps femoris, which embraces and is partly attached to the ligament. Deep to the ligament are the tendon of the popliteus and the inferior lateral genicular vessels and nerve. *The ligament has no attachment to the lateral meniscus.*

The **cruciate ligaments** are of considerable strength, and are situated in the middle of the joint, nearer to its posterior than its anterior surface. They are called *cruciate* because they cross each other somewhat like the limbs of the letter X; and have received the names *anterior* and *posterior*, from the position of their attachments to the tibia. Their position within the joint justifies their identification as collateral ligaments of the originally separate medial and lateral femoro-tibial joints (p. 518). (See also p. 529.)

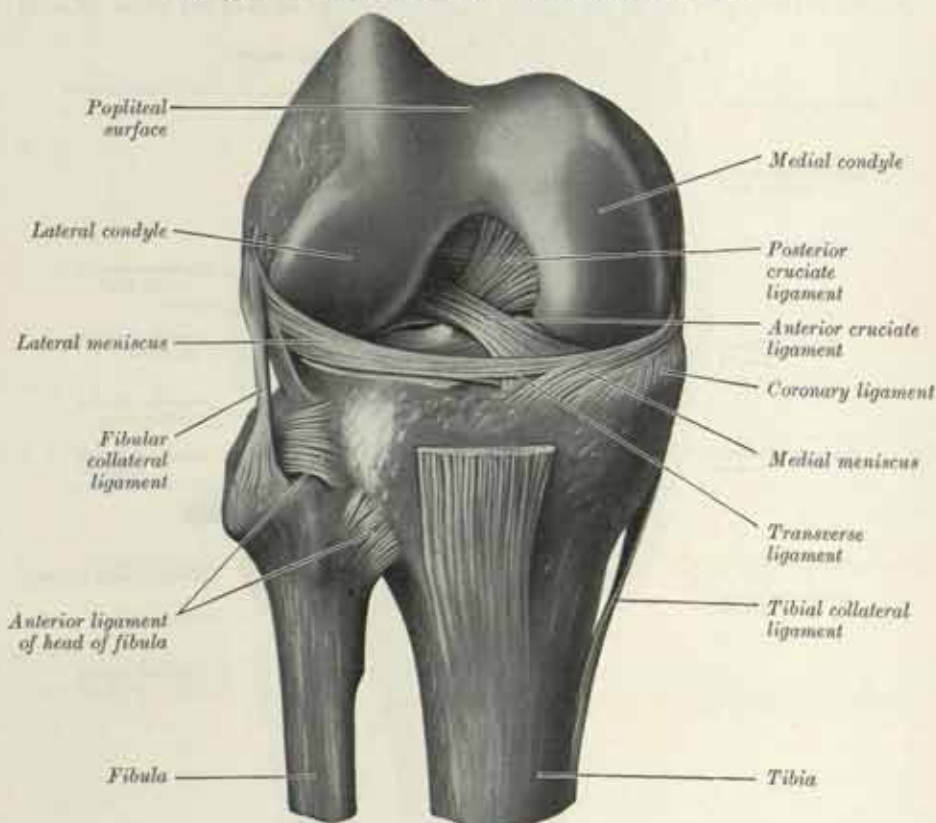
The **anterior cruciate ligament** (fig. 539) is attached to the medial part of the anterior intercondylar area of the tibia, being partly blended with the anterior end of the lateral meniscus; it passes upwards, backwards and laterally, crossing the antero-lateral aspect of the posterior cruciate ligament, and is attached to the posterior part of the medial surface of the lateral condyle of the femur.

* D. C. Brantigan and A. F. Voshell, *J. Bone Jt. Surg.*, 25, 1943.

The **posterior cruciate ligament** (figs. 538, 539) is stronger, but shorter and less oblique in its direction, than the anterior. It is attached to the posterior intercondylar area of the tibia, and to the posterior extremity of the lateral meniscus; it passes upwards, forwards and medially, to be attached to the lateral surface of the medial condyle of the femur.

The synovial membrane covers the cruciate ligaments anteriorly and on each side but posteriorly it is reflected from the sides of the posterior cruciate ligament on to the adjoining parts of the fibrous capsule. As a result of this arrangement the middle, or intercondylar, part of the posterior portion of the fibrous capsule is devoid of any synovial covering on its anterior surface. A

FIG. 538.—The right knee joint. Dissected from the front.



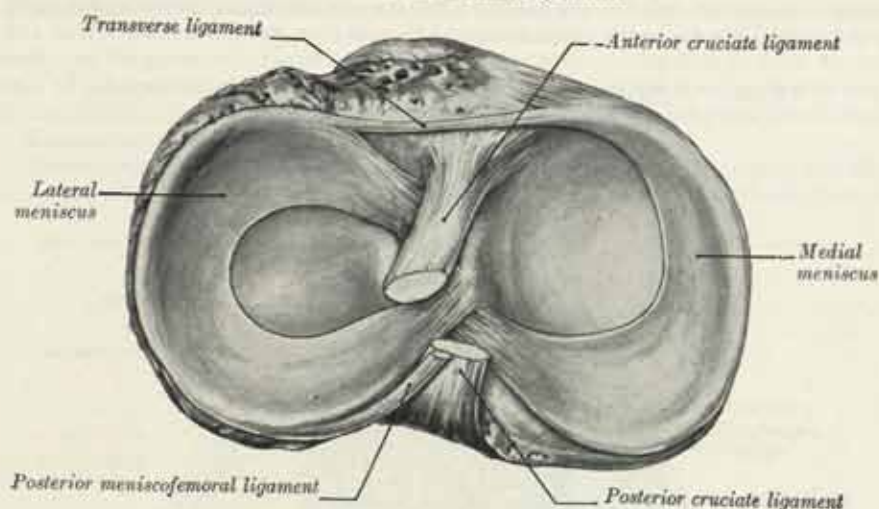
bursal recess passes in between the two ligaments from the lateral side (fig. 541) and may be deep enough to reach the medial wall of the intercondylar fossa of the femur.

The **menisci (semilunar cartilages)** (fig. 539) are two crescentic lamellæ which serve to deepen the surfaces of the upper end of the tibia for articulation with the condyles of the femur. The peripheral border of each meniscus is thick and convex; the opposite border is thin, concave, and free. The upper surfaces of the menisci are smooth and concave, and in contact with the condyles of the femur; their lower surfaces are smooth and flat, and rest upon the tibia. Each covers approximately the peripheral two-thirds of the corresponding articular surface of the tibia.

The **medial meniscus** is nearly semicircular in form, and is broader behind than in front (fig. 539); its anterior end is attached to the anterior intercondylar area of the tibia, in front of the anterior cruciate ligament, its posterior fibres being continuous with the transverse ligament. This end, or horn, of the meniscus lies in the floor of the depression which can be felt on the medial side of the upper part of the ligamentum patellæ. The posterior end of the meniscus is fixed to the posterior intercondylar area of the tibia, between the attachments of the lateral meniscus and the posterior cruciate ligament. Its peripheral border is attached to the fibrous capsule and is firmly adherent to the deep surface of the tibial collateral ligament of the knee joint. (Plate XVI.)

The **lateral meniscus** is nearly circular (fig. 539) and covers a larger portion of the articular surface than the medial. It is of the same breadth throughout its extent, and is grooved postero-laterally by the tendon of the popliteus, which separates it

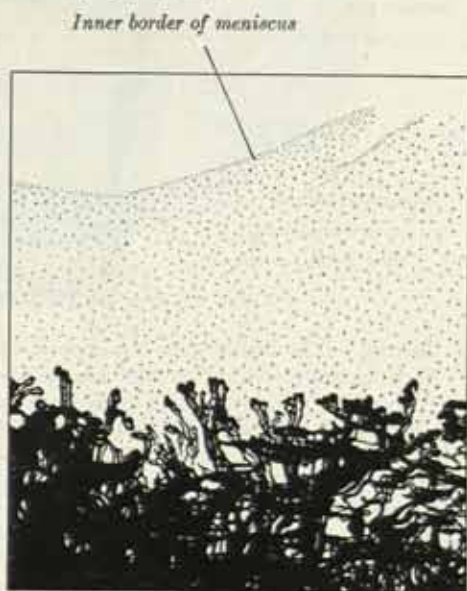
FIG. 539.—The upper end of the left tibia, showing the menisci and the lower ends of the cruciate ligaments.



from the fibular collateral ligament. Its anterior end is attached in front of the intercondylar eminence of the tibia, behind and lateral to the anterior cruciate ligament, with which it partly blends; the posterior end is attached behind the intercondylar eminence of the tibia, in front of the posterior end of the medial meniscus. The anterior attachment of the lateral meniscus is twisted so that its free margin looks backwards and upwards, its anterior end resting on a sloping shelf of bone on the front of the lateral intercondylar tubercle. Close to its posterior attachment it sends off a strong fasciculus, termed the *posterior meniscofemoral ligament* (fig. 539), which passes upwards and medially behind the posterior cruciate ligament to be inserted into the medial condyle of the femur. Another oblique band, the *anterior meniscofemoral ligament*, may arise from the posterior part of the meniscus and pass to the medial condyle of the femur in front of the posterior cruciate ligament. The tendon of the popliteus muscle intervenes between the lateral meniscus and the fibular collateral ligament. The more medial part of the tendon is inserted into the lateral meniscus.

That the menisci meet a functional need is demonstrated by the fact that they are re-formed following excision, always provided that their whole breadth is removed, as regeneration can only occur from the vascular fibroareolar tissue around its periphery (fig. 540). After complete

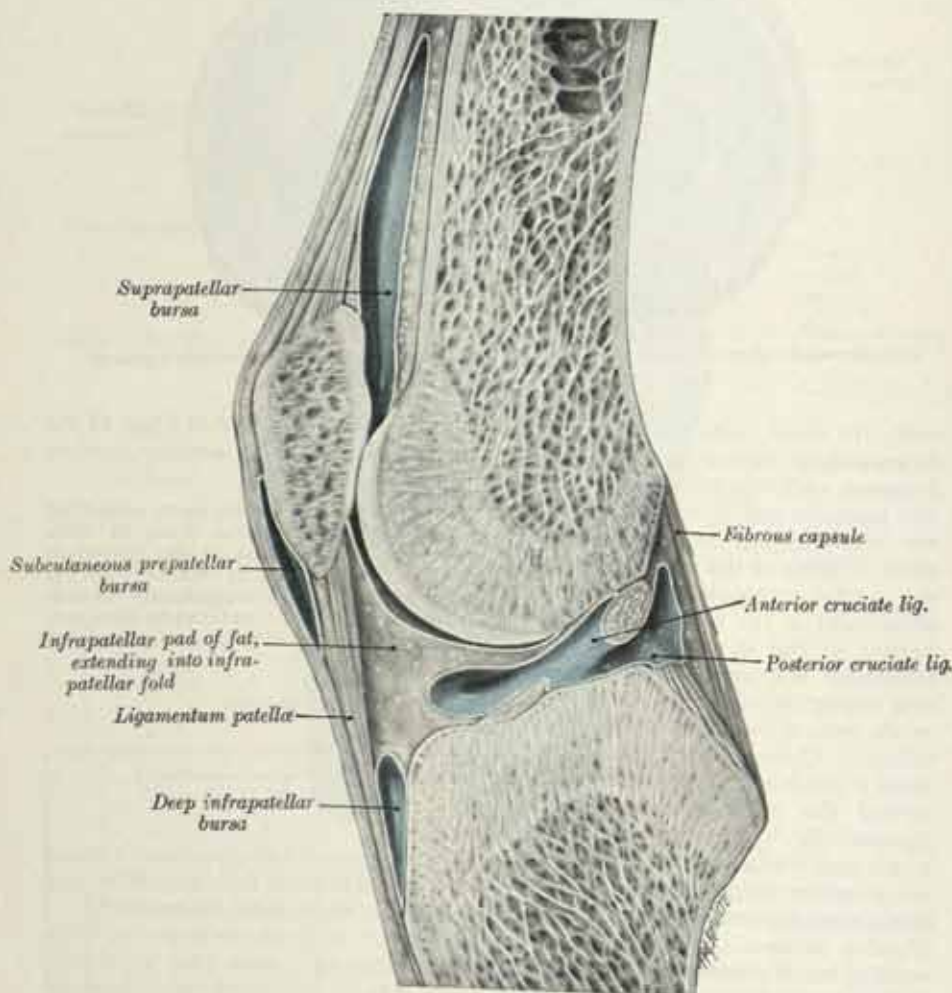
FIG. 540.—Terminal capillary loops projecting into the medial meniscus from its outer edge. Specimen cleared by the Spalteholz method after injection of vessels with 5% Indian ink suspended in reconstituted human plasma. $\times 6140$. (Reproduced by kind permission of the Editor of the *Annals of the Royal College of Surgeons*.)



excision of a meniscus and prior to re-formation, the knee joint can be used actively without any sign of instability, but if it is subjected to continued active and violent exercise, the subsequent clinical history indicates that the articular cartilage suffers permanent damage and this is attributed to inefficient lubrication during the period of regeneration (p. 453).

The **transverse ligament** (fig. 539) connects the anterior convex margin of the lateral to the anterior end of the medial meniscus; its thickness varies considerably in different subjects, and it is sometimes absent.

FIG. 541.—A sagittal section through the left knee joint. Lateral aspect. The synovial membrane is shown in colour.



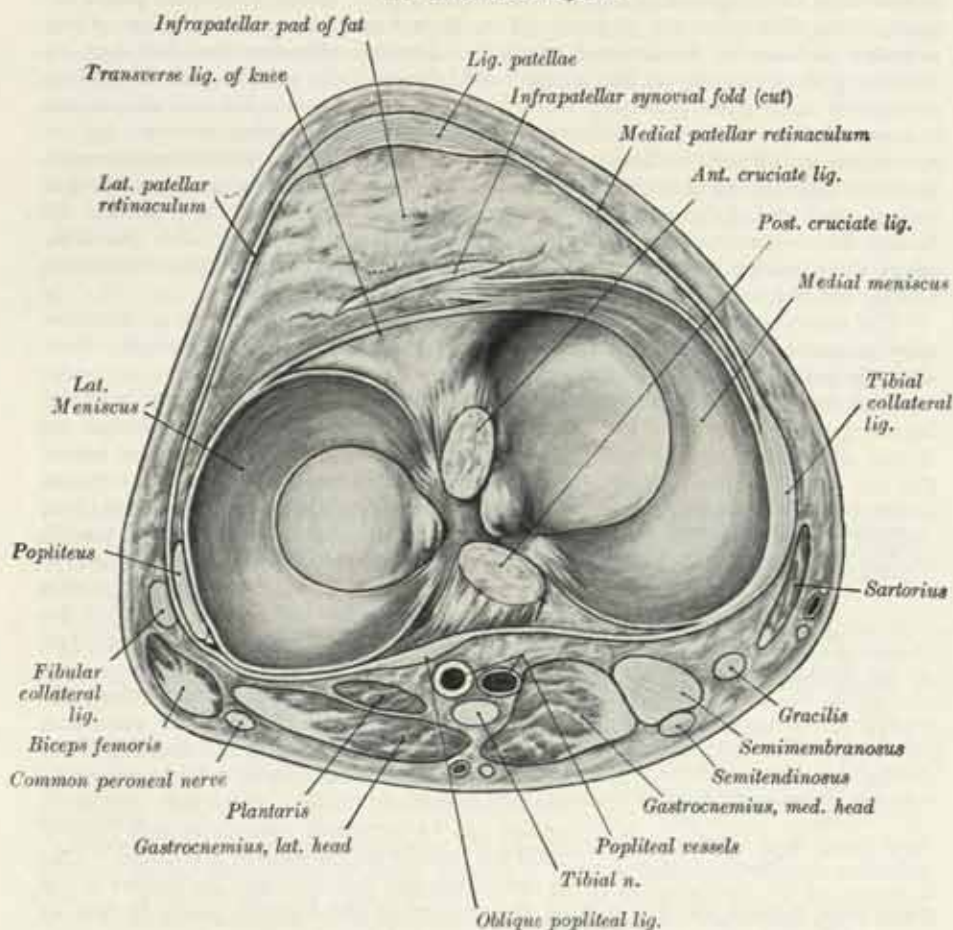
Bursæ.—The bursæ near the knee joint are the following :

In front there are four bursæ : a large one (*subcutaneous prepatellar bursa*) is interposed between the lower part of the patella and the skin, a small one (*deep infrapatellar bursa*) between the upper part of the tibia and the ligamentum patellæ, a third (*subcutaneous infrapatellar bursa*) between the lower part of the tuberosity of the tibia and the skin, and a fourth, of large size (*suprapatellar bursa*), which usually communicates with the knee joint, between the anterior surface of the lower part of the femur and the deep surface of the quadriceps femoris (fig. 541). Laterally there are four bursæ : (1) one (which sometimes communicates with the joint) between the lateral head of the gastrocnemius and the capsule ; (2) one between the fibular collateral ligament and the tendon of the biceps femoris ; (3) one between the same ligament and the tendon of the popliteus (this is sometimes only an expansion from the next bursa) ; (4) one between the tendon of the popliteus and the lateral condyle

of the femur, usually an extension from the synovial membrane of the joint. Medially, there are five bursæ: (1) one between the medial head of the gastrocnemius and the capsule: this sends a prolongation between the tendon of the medial head of the gastrocnemius and the tendon of the semimembranosus and often communicates with the joint; (2) one superficial to the tibial collateral ligament, between it and the tendons of the sartorius, gracilis, and semitendinosus; (3) one deep to the tibial collateral ligament, between it and the tendon of the semimembranosus (this is sometimes only an expansion from the next bursa); (4) one between the tendon of the semimembranosus and the medial condyle of the tibia and the medial head of the gastrocnemius. This is termed the semimembranosus bursa and may communicate with (1) above; (5) occasionally there is a bursa between the tendons of the semimembranosus and semitendinosus.

Structures around the joint.—*Anteriorly*, the quadriceps femoris covers the joint, and tendinous expansions from the vastus medialis and vastus lateralis extend

FIG. 542.—A transverse section of the left knee joint, viewed from above, to show the relations of the joint.



backwards from its margins over the *anteromedial* and *anterolateral* aspects of the capsule, respectively, forming the patellar retinacula. On the *posteromedial* side the sartorius, with the gracilis tendon lying along its posterior border, descends across the joint; on the *posterolateral* side the biceps tendon, with the common peroneal nerve on its medial side, is in contact with the fibrous capsule, which separates it from the popliteus (fig. 542). The *posterior* relations are the most numerous and the most important. The popliteal artery, with its associated lymph glands, lies on the oblique popliteal ligament; the popliteal vein is posteromedial, or medial, to the artery; and the tibial nerve is posterior to both vessels. The nerve and vessels are overlapped by the adjoining edges of the two heads of the gastrocnemius and, on the

lateral side, by the plantaris. On each side of the vessels the corresponding head of the gastrocnemius comes into intimate relation with the capsule, and on the medial side of the medial head the semimembranosus intervenes between the capsule and the semitendinosus.

The *arteries* supplying the joint are the descending genicular, the genicular branches of the popliteal, the recurrent branches of the anterior tibial, and the descending branch from the lateral circumflex femoral branch of the *arteria profunda femoris*.

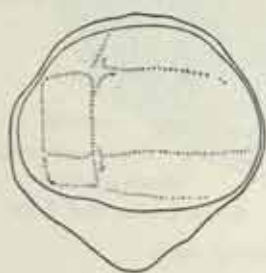
The *nerves* are derived from the obturator, the femoral, the tibial and the common peroneal nerves.

Movements.—The active movements which can be carried out at the knee joint are flexion, extension, medial rotation and lateral rotation. The movements of flexion and extension differ from those of a true hinge joint in two ways. Firstly, the axis around which the movement occurs is not fixed, but shifts forwards during extension of the leg on the thigh and backwards during flexion. Secondly extension is associated with a minor degree of medial rotation of the femur, and flexion with a corresponding degree of lateral rotation. In full flexion the posterior parts of the tibial articular surfaces are in contact with the posterior parts of the articular surfaces of the femoral condyles. During extension the tibia and its menisci glide forwards on the femoral condyles and the axis around which the movement takes place gradually shifts forwards. As a result the area of contact between the two bones moves forwards also, carrying the menisci with it. As the movement progresses the flatter curve of the femoral condyles makes contact with the tibia, and the menisci are opened out, the net result being that their anterior ends move forwards, while their posterior ends suffer little change in position. In flexion the reverse movement occurs, so that the menisci, moving with the tibia, adapt their outline to the curve of the parts of the femoral condyles which are making contact with that bone.

The movements of rotation at the knee joint have a much smaller range than the movements of flexion and extension and during their execution the menisci move with the femoral condyles on the upper articular surfaces of the tibia.

The movement of medial rotation of the femur on the tibia associated with the later stages of extension of the knee constitutes a locking mechanism, which is an asset when the knee, fully extended and under load, is subjected to strain. The axis of rotation

FIG. 543.—The posterior surface of the right patella, showing diagrammatically the areas of contact with the femur in different positions of the knee joint.



passes vertically through the lateral condyle just medial to its centre and, as a result, the medial condyle has a longer anteroposterior traverse than the lateral and suitable provision for this excursion is made by the relative sizes of the articular surfaces concerned (pp. 417, 422), but the actual mechanism of the rotation is uncertain.* The unlocking movement in the early stages of flexion is effected by the popliteus muscle. It must be observed, that locking is not necessary to ensure stability in the erect posture, for in that position the joint is not fully extended, and it can be extended voluntarily still further until the limit of the movement is reached. This is due to the fact that although the weight of the

trunk falls behind the line joining the centres of the femoral heads, it falls in front of the transverse axis of the knee joint and tends to cause hyperextension of the joint. This is prevented by the tension of the hamstring muscles, so that the quadriceps is partially relaxed in the erect attitude, and, as a result, the patella lies loosely on the front of the lower end of the femur.

In addition to the rotatory movements associated with extension and flexion, medial and lateral rotation of the leg can be effected when the joint is flexed on account of the relaxation of the fibular collateral ligament. It has been urged† that during lateral rotation of the femur or the tibia, especially in the 'unlocking' movement, the lateral meniscus is drawn backwards and downwards on to the

* C. H. Barnett, *J. Anat., Lond.*, 86, 1952.

† R. J. Last, *J. Bone and Jt. Surg.*, 32-B, 1950.

groove on the back of the lateral tibial condyle by the medial fibres of the popliteus muscle (*see also* p. 679).

At the limit of flexion the ligamentum patellæ, the cruciate ligaments and the tibial collateral ligament are tense and the posterior parts of the menisci are compressed between the femoral and tibial condyles. Flexion is checked during life by the contact of the leg with the thigh. When the knee joint is fully extended both cruciate ligaments, the posterior part of the capsule and the oblique popliteal ligament are tense and the anterior parts of the menisci are compressed between the femoral condyles and the tibia.* In the act of extending the knee the ligamentum patellæ is tightened by the quadriceps femoris, but in the erect attitude it is relaxed for reasons already stated. Medial rotation (of the tibia on the femur) is checked by the anterior cruciate ligament and the tension of the biceps femoris; lateral rotation tends to uncross and relax the cruciate ligaments, but is checked by the collateral ligaments and the tension of the medial rotators and, especially, the popliteus. The main function of the cruciate ligaments is to act as a direct bond between the tibia and femur and to prevent the former bone from being carried too far backwards or forwards. They also assist the collateral ligaments in resisting any bending of the joint to either side. The menisci ensure perfect lubrication (p. 453) and are responsible for maintaining adequate contact between the articular surfaces in all positions of the joint. They also act as cushions at the extremes of flexion and extension.

Accessory movements.—A wider range of rotation can be obtained by passive movements than can be performed actively when the joint is semiflexed, and in this position the tibia can be made to glide backwards and forwards on the femur. When the knee is slightly flexed a limited amount of adduction and abduction can be obtained, and it may be noted that these movements can be performed actively, provided that the foot is on the ground. A slight amount of separation of the femur and tibia can be obtained on strong traction.

Muscles producing the movements :

In **flexion**, the *biceps femoris*, *semitendinosus* and *semimembranosus* are the principal muscles concerned, but they receive assistance from the *gracilis*, *sartorius* and *popliteus*. When the foot is on the ground, the *gastrocnemius* and the *plantaris* are capable of participating in the movement.

In **extension**, the *quadriceps femoris* is the chief muscle concerned, but it receives some assistance from the *tensor fasciæ latæ*.

In **medial rotation of the flexed leg**, the *popliteus*, *semimembranosus* and *semitendinosus* are the chief agents, but they may be assisted by the *sartorius* and the *gracilis*.

In **lateral rotation of the flexed leg**, the *biceps femoris* is the only muscle concerned.

Applied Anatomy.—From a consideration of the construction of the knee joint, it would at first sight appear to be one of the least secure joints in the body. It is formed between the two longest bones, and therefore the amount of leverage which can be brought to bear upon it is considerable; the articular surfaces are but ill-adapted to each other, and the range of motion which it enjoys is great. All these circumstances tend to render the articulation insecure; nevertheless, on account of the powerful ligaments which bind the bones together and the strength of the muscles concerned, the joint is one of the strongest in the body, and dislocation from traumatism is a rare accident.

Injuries to one or other meniscus are of common occurrence and result from twisting strains applied to the knee when it is slightly flexed or when it is in full flexion. The damage may take the form of a tear in the substance of the cartilage or occasionally its peripheral border may be detached from the capsule over a variable extent. The torn or detached portion may become displaced towards the centre or the joint and jammed between the articular surfaces of the femur and tibia, causing locking of the joint. It should be noted that the menisci are avascular and that a tear cannot be expected to heal unless it has occurred close to the capsule (fig. 540). The medial meniscus is much more commonly affected than the lateral because it is more securely attached to neighbouring structures (p. 524) and is therefore less able to adapt itself to sudden changes of position. Further, during rotation of the flexed or partially flexed joint it has to move through a greater interval than the lateral meniscus. On the other hand, it is held † that the traction effected by the medial fibres of the popliteus muscle draws the posterior part of the lateral meniscus back-

* D. C. Brantigan and A. F. Voshell, *J. Bone Jt. Surg.*, **25**, 1943.

† R. J. Last, *loc. cit.*

wards on to the groove on the back of the lateral tibial condyle and so keeps it out of harm's way.

Injuries to the cruciate ligaments also are common and range from a simple sprain to complete rupture. The anterior ligament is usually affected. The resulting laxity of the ligament permits an excessive degree of antero-posterior gliding movement to take place between the femur and the tibia and causes instability of the joint.

Sprain or rupture of the tibial collateral ligament is a less common injury, since strain is likely to fall upon it only when the knee is in full extension.

Acute synovitis, the result of traumatism, is of frequent occurrence in the knee joint. When the cavity is distended with fluid, the swelling shows itself above and at the sides of the patella, reaching about 2.5 cm., occasionally 5 cm. or more, above the patellar surface of the femur, and extending a little higher under the vastus medialis than under the vastus lateralis. The lower level of the synovial membrane is just below the upper end of the tibia.

The bursæ about the knee joint are sometimes the seat of enlargement. The bursa between the front of the patella and the skin is frequently affected in those who are in the habit of kneeling, and the condition is known as 'housemaid's knee'. The bursa beneath the semimembranosus tendon also occasionally becomes enlarged, and forms a fluctuating swelling at the back of the knee. During extension the swelling is firm and tense; but during flexion it becomes soft, and, as the bursa often communicates with the synovial cavity of the joint, the fluid it contains can be made to disappear by pressure when the knee is flexed.

III. THE TIBIOFIBULAR JOINTS

The tibia and fibula are connected at their extremities by (1) the tibiofibular articulation above and (2) the tibiofibular syndesmosis below. (3) In addition, the shafts of the bones are connected by the crural interosseous membrane.

1. THE TIBIOFIBULAR ARTICULATION

This articulation (fig. 544) is a plane joint between the lateral condyle of the tibia and the head of the fibula. The *articular surfaces* of the bones are variable in size, form and inclination. The facet on the head of the fibula is generally elliptical or circular in shape and flat or slightly grooved. These facets are covered with cartilage, and the bones are connected by a fibrous capsule and by anterior and posterior ligaments of the head of the fibula.

The **fibrous capsule** is attached to the margins of the articular facets on the tibia and fibula; it is much thicker in front than behind. Not infrequently the synovial membrane of the joint is continuous with that of the knee joint through the subpopliteal recess. The **anterior ligament** consists of two or three flat bands, which pass obliquely upwards from the front of the head of the fibula to the front of the lateral condyle of the tibia. The **posterior ligament** is a thick band, which passes obliquely upwards from the back of the head of the fibula to the back of the lateral condyle of the tibia. It is covered by the tendon of the popliteus.

2. THE CRURAL INTEROSSEOUS MEMBRANE

The **crural interosseous membrane** connects the interosseous borders of the tibia and fibula, and separates the muscles on the front from those on the back of the leg. The anterior tibial artery passes to the front of the leg through a large oval opening in the uppermost part of the membrane, and the perforating branch of the peroneal artery pierces its lower part. It consists of oblique fibres, which for the most part run downwards and laterally; a few, however, pass downwards and medially, including a bundle which forms the upper border of the opening for the anterior tibial artery. The membrane is continuous below with the interosseous ligament of the tibiofibular syndesmosis. It is in relation, in front, with the tibialis anterior, extensor digitorum longus, extensor hallucis longus, peroneus tertius, and the anterior tibial vessels and deep peroneal nerve; behind, with the tibialis posterior and flexor hallucis longus.

3. THE TIBIOFIBULAR SYNDESMOSIS

This joint is formed by the rough, convex surface on the medial side of the lower end of the fibula, and the rough, concave surface of the fibular notch of the

tibia. Below, these surfaces are separated for a distance of about 4 mm. by an upward prolongation of the synovial membrane of the talocrural joint and may be covered with articular cartilage in the lowest mm.

The **anterior tibiofibular ligament** (fig. 548) is a flattened band which extends obliquely downwards and laterally between the adjacent margins of the tibia and fibula, on the front of the syndesmosis.

The **posterior tibiofibular ligament** (fig. 548), stronger than the preceding, is disposed in a similar manner on the posterior surface of the syndesmosis. Its lower and deep portion forms the **inferior transverse ligament**—a strong, thick band of yellowish fibres which passes transversely from the upper part of the lateral malleolar fossa of the fibula to the posterior border of the articular surface of the tibia, almost as far as the medial malleolus. The inferior transverse ligament projects below the margins of the bones, and forms part of the articulating surface for the talus. It contains a number of yellow elastic fibres.

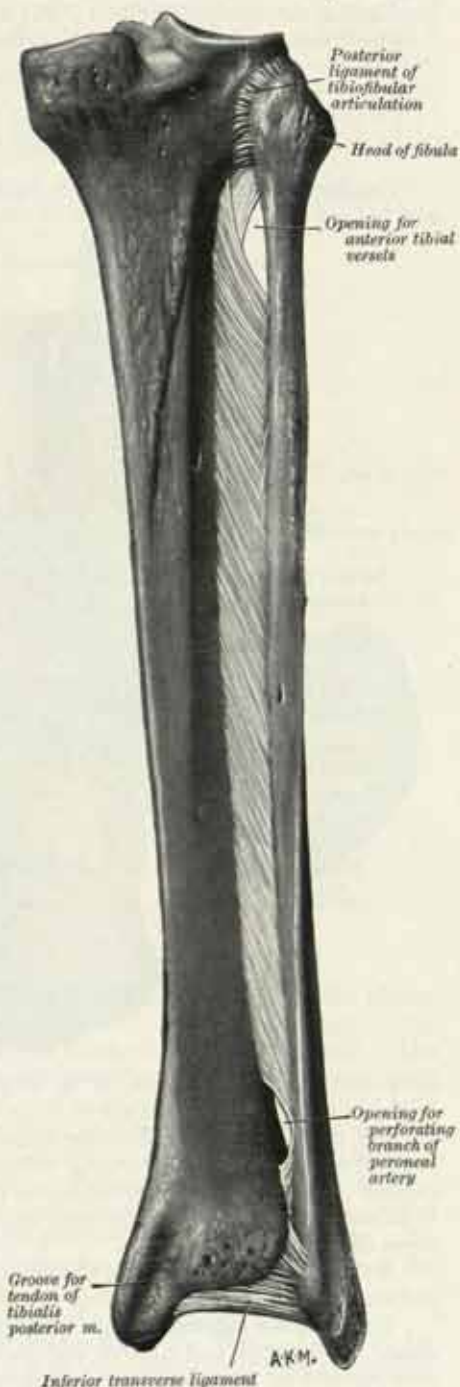
The **interosseous ligament** is continuous, above, with the crural interosseous membrane and consists of numerous, short, strong bands which pass between the adjacent rough surfaces of the tibia and fibula, and constitute the chief bond of union between the lower ends of the bones.

Movements.—The joints between the tibia and fibula permit very slight movements. Owing to the varying inclination of the articular surface on the talus for the lateral malleolus, the fibula undergoes a small amount of lateral rotation during dorsiflexion of the ankle.*

IV. THE TALOCRURAL ARTICULATION (ANKLE JOINT)

The talocrural joint is a ginglymus, or hinge joint. The lower end of the tibia and its malleolus, the malleolus of the fibula, and the inferior transverse tibiofibular ligament enter into its formation, and together form a mortise for the reception of the body of the talus. The line of the joint can be gauged from the anterior margin of the lower end of the tibia, which can be felt through the skin in the living subject when the overlying tendons are relaxed. The *articular surfaces* are covered with hyaline cartilage. The trochlear surface of the talus, which is convex from before backwards and gently concave from side to side, is *wider in front than behind*, and the inferior articular

FIG. 544.—The crural interosseous membrane. Posterior aspect.



* C. H. Barnett and J. R. Napier, *J. Anat., Lond.*, 86, 1952.

surface of the tibia is reciprocally shaped. The articular surface for the medial malleolus is restricted to the upper part of the medial surface of the talus. It is flat and comma-shaped, being deeper in front than behind. The lateral surface of the talus, which is triangular in outline, is concave from above downwards and adapts itself to the articular surface of the lateral malleolus, which is convex from above downwards. (Plates XVII and XVIII.)

The bones are connected by the following ligaments:

Articular capsule.

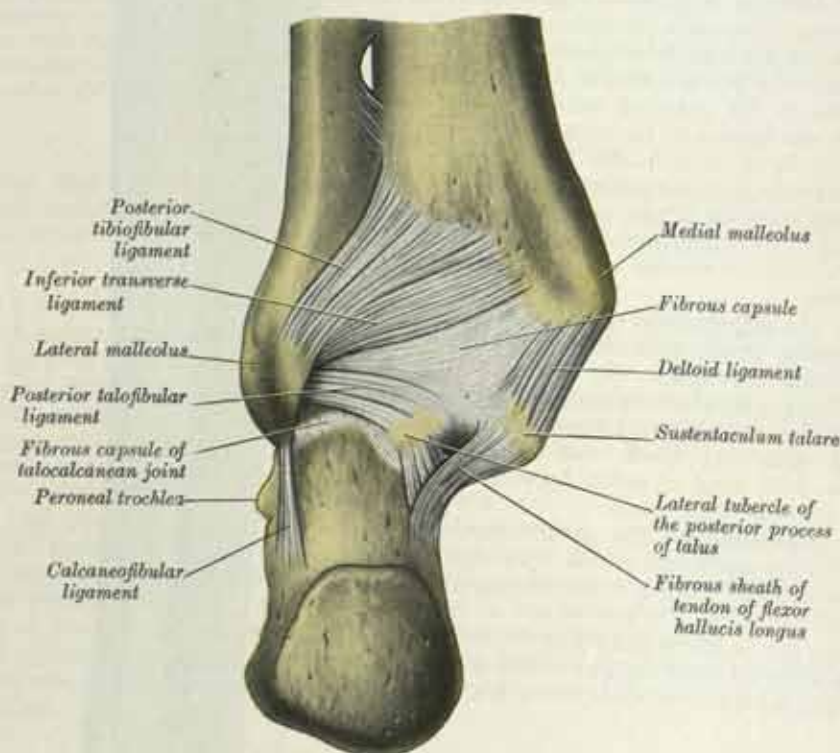
Deltoid.

Anterior and posterior talofibular.

Calcaneofibular.

The **fibrous capsule** surrounds the joint; it is thin and membranous in front and behind and is attached above to the borders of the articular surfaces of the

FIG. 545.—The left talocrural articulation. Posterior aspect.



tibia and malleoli; below, it is attached to the talus close to the margins of the trochlear surface except in front where it is attached to the dorsum of the neck of the talus at some distance in front of the superior articular surface. It is supported on each side by strong collateral ligaments. The posterior part of the capsule consists principally of transverse fibres. It blends with the inferior transverse fossa of the fibula.

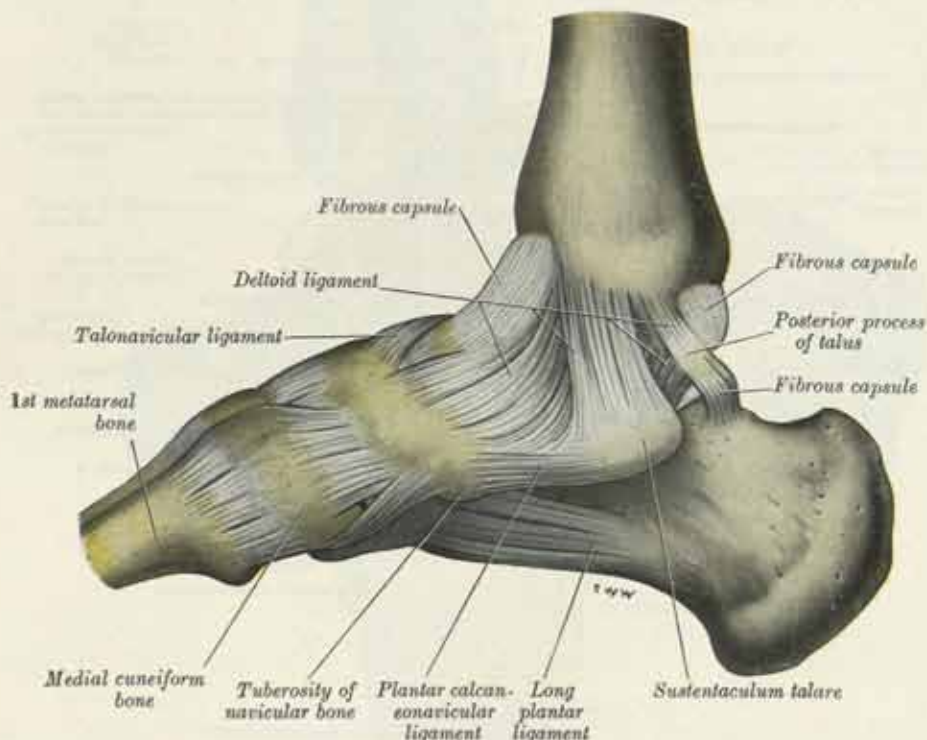
A synovial membrane lines the fibrous capsule, and the joint cavity ascends for a short distance between the tibia and fibula (fig. 549).

The **deltoid ligament** (figs. 546, 549) is a strong, triangular band, attached, above, to the apex and anterior and posterior borders of the medial malleolus. It consists of two sets of fibres, superficial and deep. Of the superficial fibres the anterior (*tibionavicular*) pass forwards to be attached to the tuberosity of the navicular bone, and immediately behind this they blend with the tuberosity of the plantar calcaneonavicular ligament; the middle fibres (*tibiocalcanean*) descend almost perpendicularly and are fixed to the whole length of the sustentaculum tali of the calcaneus; the posterior fibres (*posterior tibiotalar*) pass backwards and

laterally to be attached to the medial side of the talus, and to its medial tubercle. The deep fibres (*anterior tibiotalar*) are well developed and are fixed, above, to the tip of the medial malleolus, and below, to the non-articular part of the medial surface of the talus. The deltoid ligament is crossed by the tendons of the *tibialis posterior* and *flexor digitorum longus*.

The **anterior talofibular ligament** (fig. 548) passes from the anterior margin of the fibular malleolus, forwards and medially, to the talus, where it is attached in front of the lateral articular facet and to the lateral aspect of the neck. The **posterior talofibular ligament** (fig. 545), strong and deeply seated, runs almost horizontally from the lower part of the lateral malleolar fossa to the lateral tubercle of the posterior process of the talus. The **calcaneofibular ligament** (fig. 548) is a long

FIG. 546.—The ligaments of the right talocrural and tarsal joints. Medial aspect.



rounded cord, running from the depression in front of the apex of the fibular malleolus downwards and backwards to a tubercle on the lateral surface of the calcaneus. It is crossed by the tendons of the *peroneus longus* and *brevis*. The foregoing three ligaments together constitute the *lateral ligament* of the talocrural joint.

Relations.—The tendons, vessels, and nerves in relation with the joint are: in front, from the medial side, the *tibialis anterior*, *extensor hallucis longus*, *anterior tibial vessels*, *deep peroneal nerve*, *extensor digitorum longus*, and *peroneus tertius*; behind, from the medial side, the *tibialis posterior*, *flexor digitorum longus*, *posterior tibial vessels*, *tibial nerve*, *flexor hallucis longus*; and, in the groove behind the fibular malleolus, the tendons of the *peroneus longus* and *brevis* (fig. 547).

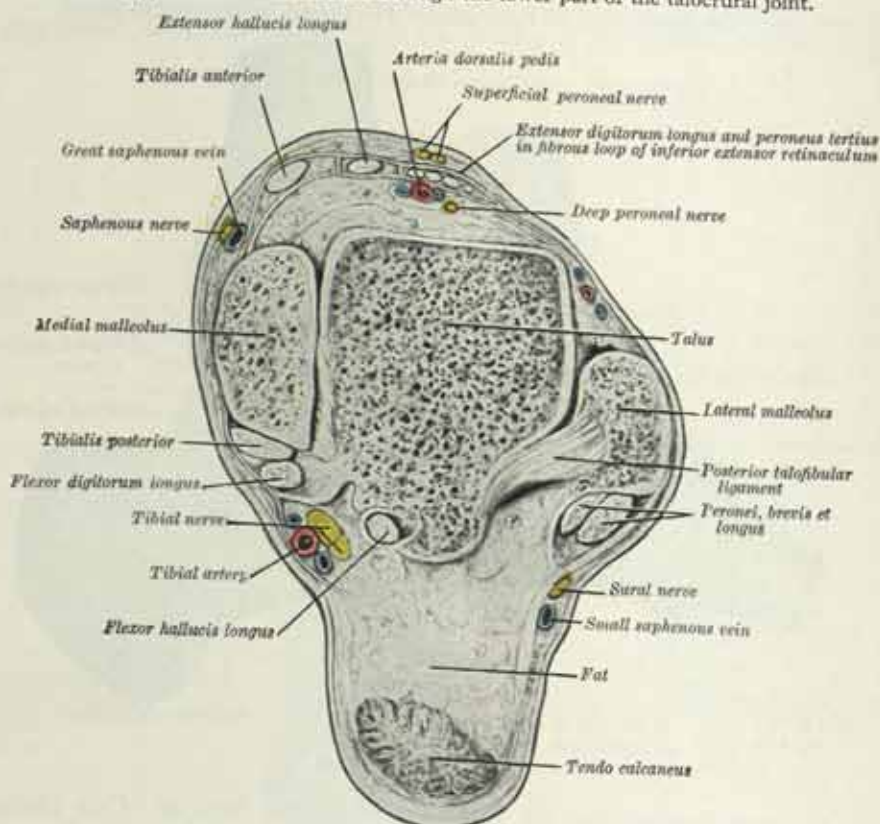
The *arteries* supplying the joint are derived from the malleolar branches of the *anterior tibial* and from the *peroneal*.

The *nerves* are derived from the *deep peroneal* and *tibial nerves*.

Movements.—When the body is in the erect position the foot is at right angles to the leg. The *active movements* of the talocrural joint are those of *dorsiflexion* and *plantar flexion*; in *dorsiflexion* the angle between the front of the leg and the dorsum of the foot is diminished; in *plantar flexion* the angle is increased, the heel being raised and the toes pointed downwards. The malleoli embrace the talus in the position of rest, and no appreciable degree of side-to-side movement can occur without stretching of the ligaments of the *tibiofibular syndesmosis*, and slight

bending of the fibula. The superior articular surface of the talus is broader in front than behind. In dorsiflexion, therefore, greater space is required between the two malleoli. This is obtained by a slight separation of the lower ends of the tibia and fibula and is consequent on slight movement at the tibiofibular syndesmosis; this movement is facilitated by a minor degree of gliding at the tibiofibular joint. The deltoid ligament is exceedingly strong—so much so, that it usually resists a force which fractures the process of bone to which it is attached. Its middle portion, together with the calcaneofibular ligament, binds the bones of the leg firmly to the foot, and resists displacement in every direction. The posterior talofibular ligament assists the calcaneofibular in resisting displacement of the foot backwards, and

FIG. 547.—Transverse section through the lower part of the talocrural joint.



deepens the cavity for the reception of the talus. The anterior talofibular ligament is a security against displacement of the foot forwards. Plantar flexion of the foot is limited by the tension of the opposing muscles, by the anterior fibres of the deltoid and by the anterior talofibular ligament. Dorsiflexion of the foot is limited by the tension of the tendo calcaneus, by the posterior fibres of the deltoid and by the calcaneofibular ligament (see also pp. 543-545).

Accessory movements.—Slight amounts of side to side gliding movement, rotation, abduction and adduction are permitted, when the foot is in plantar flexion.

Muscles producing the movements, (see also pp. 543-545):

In **dorsiflexion** the *tibialis anterior* is the most important factor, but it receives appreciable assistance from the extensor digitorum longus, the extensor hallucis longus and the peroneus tertius.

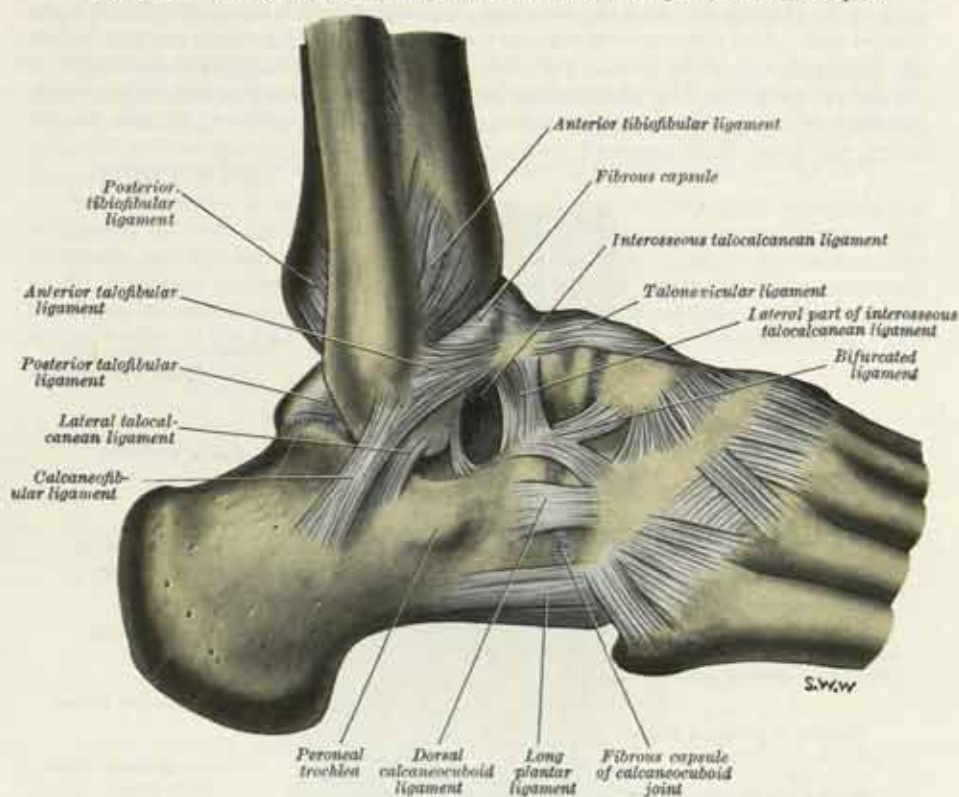
In **plantar flexion**, the *gastrocnemius* and the *soleus* are the chief agents, assisted to a lesser degree by the plantaris, the *tibialis posterior*, the *flexor hallucis longus* and the *flexor digitorum longus*.

Applied Anatomy.—Owing to the protection afforded to the talus by the tibiofibular mortise, the talocrural joint is a very stable articulation and dislocation is rare unless one of the malleoli is fractured. So-called sprains of the talocrural joint are almost

always abduction sprains of the subtalar joints, although some of the fibres of the deltoid ligament also are torn. True sprains of the talocrural joint are usually caused by forced plantar flexion and the result in tearing of the capsular ligament on the front of the joint and bruising by impaction of the structures at the back of the joint.

When disease or injury of the talocrural joint is likely to lead to ankylosis, the joint is kept slightly plantarflexed.

FIG. 548.—The ligaments of the right talocrural and tarsal joints. Lateral aspect.



V. THE INTERTARSAL JOINTS

1. THE SUBTALAR (TALOCALCANEAN) JOINT

There are two articulations between the calcaneus and talus, an anterior and a posterior. These two joints form a single functional unit which is generally termed by clinicians the subtalar joint, but this term is used here for the posterior joint only, the anterior being described as part of the talocalcaneonavicular joint (p. 536).

The subtalar joint, as defined above, is formed between the concave posterior calcaneal facet on the inferior surface of the talus and the convex posterior facet on the upper surface of the calcaneus. The two bones are connected by a fibrous capsule and by lateral, medial and interosseous talocalcaneal ligaments.

The **fibrous capsule** (fig. 551) envelops the joint, and consists for the most part, of short fibres; it is split into slips, and between these there is only a weak fibrous investment. It is lined with synovial membrane, and the joint-cavity does not communicate with any of the other tarsal joints.

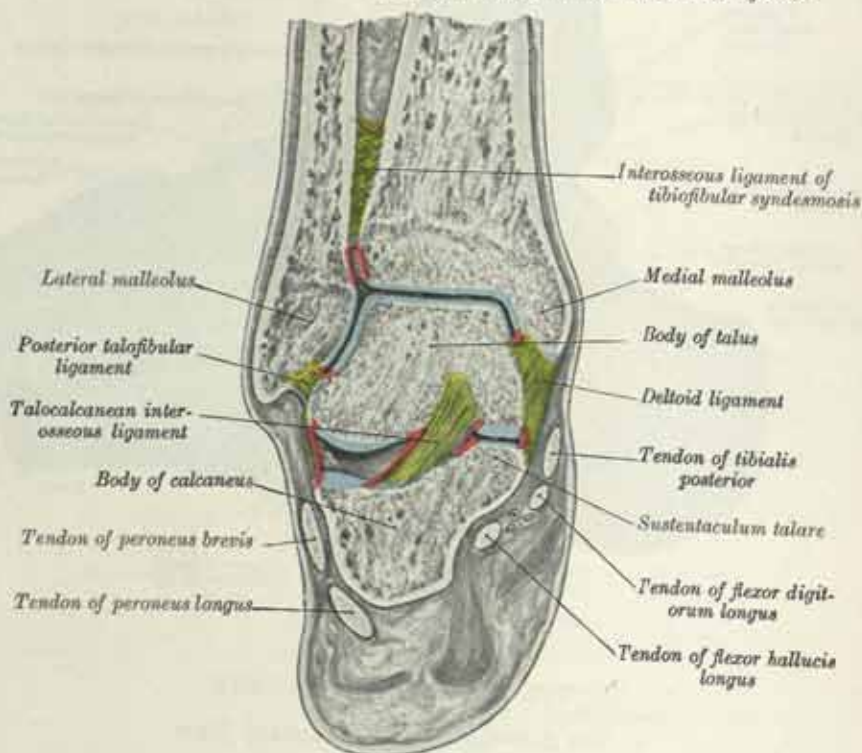
The **lateral talocalcaneal ligament** (fig. 548) is a short, flattened fasciculus, which passes downwards and backwards from the lateral tubercle of the talus to be attached to the lateral surface of the calcaneus, above and in front of the calcaneofibular ligament.

The **medial talocalcaneal ligament** connects the medial tubercle on the posterior surface of the talus with the back of the sustentaculum talare and the medial surface of the calcaneus immediately behind this. Its fibres blend with those

of the deltoid ligament; the most posterior fibres line the groove for the flexor hallucis longus between the talus and the calcaneus.

The **interosseous talocalcaneal ligament** (figs. 549, 551) forms the chief bond of union between the bones and occupies the non-articular interval between the subtalar and talocalcaneonavicular joints. It comprises two distinct parts which are placed medially and laterally respectively. The medial part, which is often referred to as the interosseous talocalcaneal ligament, occupies the inner, narrow part of the channel between the talus and calcaneus which is sometimes termed the *canalis tarsi*. It is composed of anterior and posterior lamellæ which are attached to the floor and roof of the *canalis tarsi* and whose fibres run in opposite directions in an oblique manner. The anterior lamella has often been considered as the posterior ligament of the talocalcaneonavicular joint and the posterior lamella as the

FIG. 549.—A coronal section through the left talocrural and talocalcaneal joints.



anterior ligament of the subtalar joint. Lateral to, but usually distinct from the lamellæ is the attachment of the stem of the inferior extensor retinaculum to the calcaneus. The lateral part of the interosseous ligament is frequently termed the *cervical ligament* of the talus. It occupies the outer expanded part of the channel between the talus and calcaneus which can be distinguished as the *sinus tarsi*. It is attached below to a tubercle in the floor of the sinus in front of the attachment of the inferior extensor retinaculum and runs medially and slightly upwards to a tubercle on the inferior and lateral aspect of the neck of the talus.* It is rendered taut when the foot is inverted and prevents the occurrence of too great a degree of this movement.

Movements.—The movements permitted between the talus and calcaneus are closely associated with the movements at the talocalcaneonavicular joint and will be described with them.

2. THE TALOCALCANEONAVICULAR JOINT

This articulation is a restricted form of ball-and-socket joint: the rounded head of the talus being received into the concavity formed by the posterior surface of the navicular, the anterior upper articular surface of the calcaneus, and the upper sur-

* E. Barclay Smith, *J. Anat., Lond.*, 30, 1896. R. J. Last, *J. Bone Jt. Surg.*, 34B, 1952.

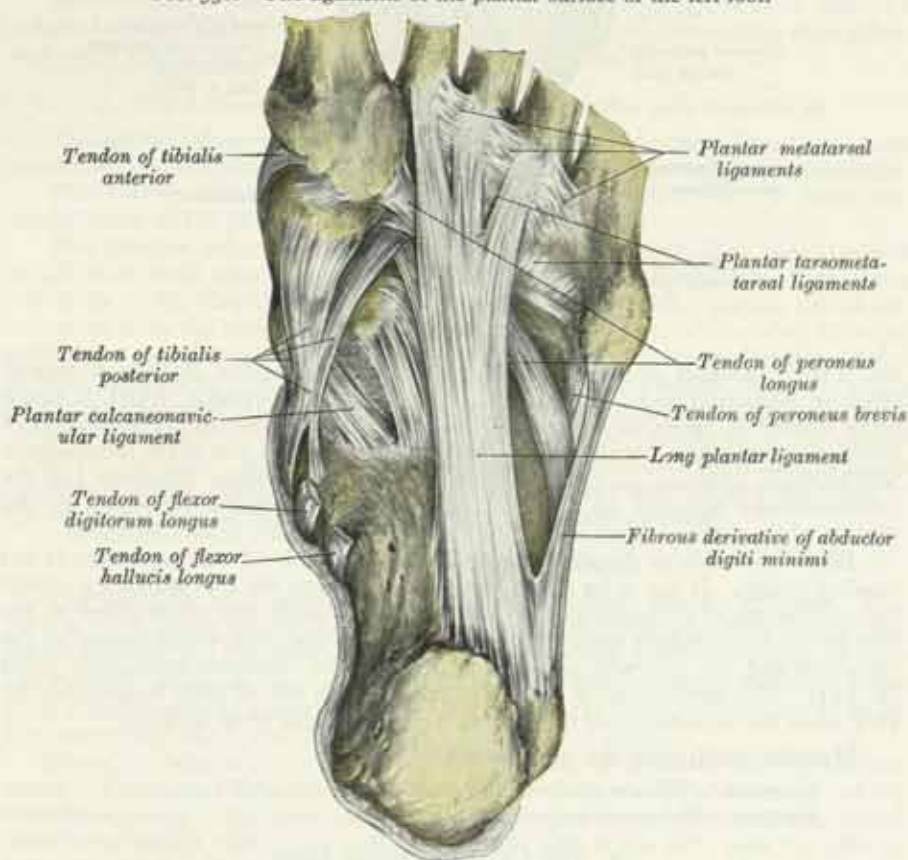
face of the plantar calcaneonavicular ligament. In the living subject the position of the joint can be gauged from the head of the talus, which can be both seen and felt 3 cm. in front of the lower end of the tibia, when the foot is passively inverted. The bones forming the joint are connected by a fibrous capsule, and by the talonavicular, the plantar calcaneonavicular and the calcaneonavicular part of the bifurcated ligament.

The **fibrous capsule** is imperfectly developed except posteriorly, where it is considerably thickened and forms the anterior part of the interosseous ligament which fills the sinus tarsi.

The **talonavicular ligament** (fig. 546) is a broad, thin band, connecting the neck of the talus to the dorsal surface of the navicular bone; it is covered with the extensor tendons. The plantar calcaneonavicular ligament (p. 539) is the plantar, and the calcaneonavicular part of the bifurcated ligament (*vide infra*) the lateral ligament for this joint.

Movements.—A considerable range of gliding and rotatory movement is permitted at both the talocalcaneal and the talocalcaneonavicular joints. The calcaneus and the navicular, carrying the foot with them, can be moved medially on the talus in a combination of gliding movement and rotation. This movement results in the elevation of the medial border and a corresponding depression of the lateral border of the foot, so that the plantar aspect of the foot faces medially. This

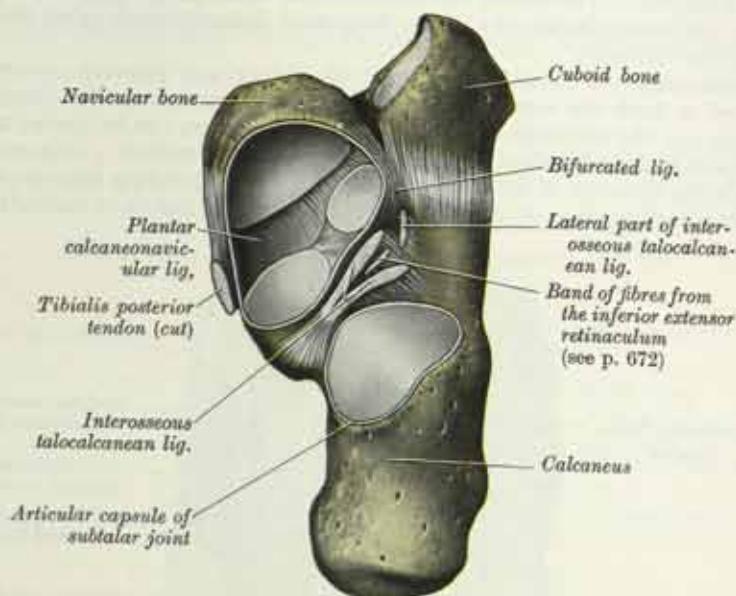
FIG. 550.—The ligaments of the plantar surface of the left foot.



is the position of *inversion*. The greater part of the movement of inversion occurs at the two joints underlying the talus, i.e., at the subtalar joint and at the articulation between the head of the talus and the sustentaculum tali, front of the calcaneus and spring ligament. The surfaces of these two joints are curved in opposite directions and the movements occurring at them have been likened to the movements between the radius and ulna in supination and pronation. The axis of the movements runs from behind, forwards, upwards and medially, passing from the back of the calcaneus, through the sinus tarsi to emerge at the superior and medial aspect of

the neck of the talus.* The movement of the calcaneus around the talus is accompanied by movement at the *transverse tarsal articulation* which comprises the talonavicular and the calcaneocuboid articulations. These lie almost in the same transverse plane and during inversion the navicular rotates on the head of the talus whilst the cuboid glides downwards in the curved groove on the front of the calcaneus. It should be noted that inversion is in reality a combination of adduction of the front part of the foot and partial 'supination'. The range of the movement is appreciably increased in plantar flexion of the foot, for in this position the narrow part of the trochlear surface of the talus occupies the tibiofibular mortise

FIG. 551.—The right talocalcaneal and talocalcaneonavicular joints exposed from above by removal of the talus.



and a slight amount of movement of the talus in the mortise gives an increased range of adduction and 'supination'. The opposite movement, which is much more limited in range, is termed *eversion*. The chief factor in the limitation of inversion is the tension of the peronei and the strong lateral part of the interosseous talocalcaneal ligament (p. 536). The other tarsal interosseous ligaments and the calcaneofibular ligament are less important factors. Eversion is arrested by the tension of the tibialis anterior and tibialis posterior and the deltoid ligament.

The movements as described occur when the foot is off the ground or is not bearing weight. It has to be noted, however, that when the foot is bearing weight the movements of inversion and eversion are still possible and are imposed on the foot by the body-weight acting through the tibia on the talus, which moves on the calcaneus and the navicular at the talocalcaneal and talocalcaneonavicular joints (p. 543). The movements of inversion and eversion are of great importance for they allow the adjustment of the foot to uneven surfaces when walking.

Muscles producing the movements

Inversion.—Tibialis anterior and posterior.

Eversion.—Peroneus longus and brevis.

3. THE CALCANEOCUBOID JOINT

The articular surfaces of the calcaneocuboid joint, which lies 2 cm. behind the tubercle on the base of the fifth metatarsal bone, are somewhat saddle-shaped. The ligaments of the joint are: the articular capsule, the calcaneocuboid portion of the bifurcated ligament, the long plantar and the plantar calcaneocuboid.

The **fibrous capsule** is slightly thickened over the dorsal surface of the joint. This thickening is sometimes termed the *dorsal calcaneocuboid ligament*. The synovial membrane is distinct from that of the other tarsal articulations (fig. 552).

* E. Shephard, *J. Bone Jt. Surg.*, 33B, 1951.

The **bifurcated ligament** (figs. 548, 551) is a strong band attached behind to the anterior part of the upper surface of the calcaneus and dividing in front in a Y-shaped manner into a calcaneocuboid and a calcaneonavicular ligament. The *calcaneocuboid ligament* is fixed to the dorsal part of the medial side of the cuboid bone and forms one of the principal bonds between the first and second rows of the tarsal bones. The *calcaneonavicular ligament* is attached to the dorsolateral aspect of the navicular bone.

The **long plantar ligament** (fig. 550), which is the longest of the tarsal ligaments, is attached posteriorly to the plantar surface of the calcaneus in front of the medial and lateral tubercles (Fig. 458), and anteriorly to the ridge and tuberosity on the plantar surface of the cuboid bone, the more superficial fibres being continued forwards to the bases of the second, third, and fourth metatarsal bones. This ligament converts the groove on the plantar surface of the cuboid bone into a tunnel for the tendon of the peroneus longus. It possesses great strength and is an important factor in resisting flattening of the lateral longitudinal arch of the foot (p. 545).

The **plantar calcaneocuboid (short plantar) ligament** lies nearer to the bones than the preceding ligament, from which it is separated by a little areolar tissue. It is a short but wide band of great strength, and stretches from the anterior tubercle of the calcaneus and the depression in front of it, to the adjoining part of the plantar surface of the cuboid bone. Like the preceding ligament, it resists flattening of the lateral longitudinal arch of the foot.

Movements.—The movements permitted between the calcaneus and the cuboid bone are limited to slight gliding and rotation of the bones upon each other, and occur during the movements of inversion and eversion.

4. THE LIGAMENTS CONNECTING THE CALCANEUS AND NAVICULAR

Though the calcaneus and the navicular bone do not articulate directly, they are connected by two ligaments: the calcaneonavicular and the plantar calcaneonavicular.

The **calcaneonavicular ligament** has been described above; it forms the medial band of the bifurcated ligament.

The **plantar calcaneonavicular** or '**spring**' ligament (figs. 546, 550) is a broad, thick band connecting the anterior margin of the sustentaculum talare of the calcaneus to the plantar surface of the navicular bone. This ligament unites the calcaneus with the navicular bone, and lies below the head of the talus, forming part of the articular cavity in which the head is received; it resists flattening of the medial longitudinal arch of the foot (p. 544). The *dorsal surface* of the ligament presents a triangular fibrocartilaginous facet upon which a portion of the head of the talus rests (fig. 551). Its *plantar surface* is supported by the tendon of the tibialis posterior, medially; and by the tendons of the flexor hallucis longus and the flexor digitorum longus, laterally; its *medial border* is blended with the anterior fibres of the superficial part of the deltoid ligament of the talocrural joint.

5. THE CUNEONAVICULAR JOINT

The navicular bone articulates in front with the three cuneiform bones. The joint is of the plane variety and its articular capsule is continuous with those of the intercuneiform and the cuneocuboid joints. Its synovial cavity is continuous with the synovial cavities of these joints and with the synovial cavities of the second and third cuneometatarsal joints and of the intermetatarsal joints between the bases of the second and third, and third and fourth metatarsal bones.

Dorsal and plantar ligaments connect the navicular bone to each of the cuneiform bones. The **dorsal ligaments** are three small fasciculi, one attached to each of the cuneiform bones. The fasciculus connecting the navicular bone with the medial cuneiform bone is continuous round the medial side of the joint with the plantar ligament which unites these two bones. The **plantar ligaments** have a similar arrangement to the dorsal, and are strengthened by slips from the tendon of the tibialis posterior.

6. THE CUBOIDEONAVICULAR JOINT

The cuboideonavicular joint is usually a syndesmosis, and the two bones are connected by dorsal, plantar and interosseous ligaments. The **dorsal ligament** extends obliquely forwards and laterally, while the **plantar** passes nearly transversely from the cuboid bone to the navicular bone. The **interosseous ligament**

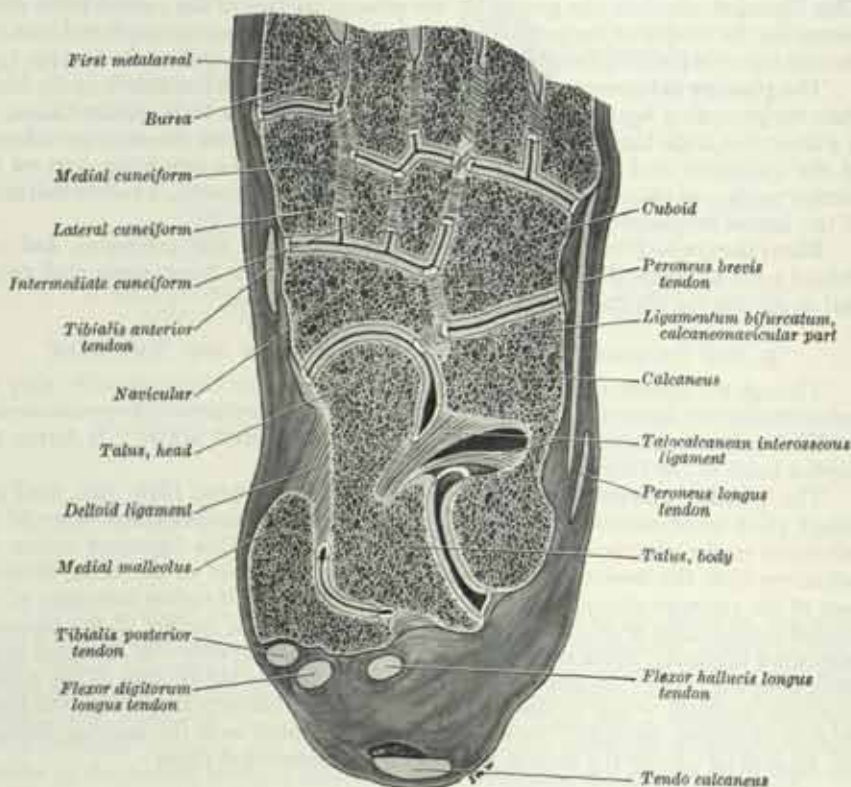
consists of strong transverse fibres, and connects the rough non-articular portions of the adjacent surfaces of the two bones (fig. 552).

Not infrequently the syndesmosis is replaced by a synovial joint. In that event the joint is of the plane variety and its articular capsule and synovial cavity are continuous with those of the cuneonavicular joint.

7. THE INTERCUNEIFORM AND CUNEOCUBOID JOINTS

The intercuneiform joints and the joint between the lateral cuneiform bone and the cuboid are all synovial in character and of the plane variety. Their articular capsules and synovial cavities are continuous with those of the cuneonavicular joint.

FIG. 552.—An oblique section through the right foot, showing the synovial cavity of the intertarsal and tarsometatarsal joints. Viewed from above.



Note.—The section passed below the joint between the medial cuneiform bone and the base of the second metatarsal; no synovial joint was present between the navicular and cuboid bones.

The bones are connected together by dorsal, plantar, and interosseous ligaments.

The **dorsal** and **plantar ligaments** each consist of three transverse bands: one connects the medial and intermediate cuneiform bones, another the intermediate and lateral cuneiform bones, and another the lateral cuneiform and cuboid bones. The plantar ligaments are strengthened by slips from the tendon of the tibialis posterior. The **interosseous ligaments** connect the rough non-articular portions of the adjacent surfaces of the bones and possess considerable strength; they resist depression of the transverse arch of the foot (p. 545).

Movements.—The movements permitted at the cuneonavicular, cuboideonavicular, intercuneiform and cuneocuboid joints are limited to a slight amount of gliding of the bones concerned on each other, and cannot be performed voluntarily when the foot is raised from the ground. They occur when load is taken by the anterior part of the foot, *e.g.* in starting to run or jump, etc., and greatly increase the suppleness of the foot.

VI. THE TARSOMETATARSAL JOINTS

These are synovial joints of the plane variety. The first metatarsal bone articulates with the medial cuneiform bone; the second is dovetailed in between

the medial and lateral cuneiform bones, articulating by its base with the intermediate cuneiform bone; the third articulates with the lateral cuneiform bone; the fourth, with the cuboid and lateral cuneiform bones; and the fifth with the cuboid bone. These joints lie on a line joining the tubercle of the fifth metatarsal bone to the tarsometatarsal joint of the great toe, with the exception of the joint between the second metatarsal and the intermediate cuneiform bone, which lies 2 mm. to 3 mm. proximal to the line of the others (fig. 552). The first joint possesses an independent articular capsule and synovial cavity. The articular capsules and synovial cavities of the second and third joints are continuous with those of the intercuneiform and cuneonavicular joints, but are shut off from those of the fourth and fifth joints by an interosseous ligament which passes between the lateral cuneiform bone and the base of the fourth metatarsal. The bones are connected by dorsal and plantar tarso-metatarsal and interosseous cuneometatarsal ligaments.

The **dorsal ligaments** are strong, flat bands. The first metatarsal is joined to the medial cuneiform bone by an articular capsule; the second metatarsal receives three bands, one from each cuneiform bone; the third, one from the lateral cuneiform bone; the fourth, one from the lateral cuneiform bone, and another from the cuboid bone; and the fifth, one from the cuboid bone.

The **plantar ligaments** consist of longitudinal and oblique bands, disposed with less regularity than the dorsal ligaments. Those for the first and second metatarsal bones are the strongest; the second and third metatarsal bones are joined by oblique bands to the medial cuneiform bone; the fourth and fifth metatarsal bones are connected by a few fibres to the cuboid bone.

The **interosseous cuneometatarsal ligaments** are three in number. The first is the strongest and passes from the lateral surface of the medial cuneiform bone to the adjacent angle of the second metatarsal bone and is constant (fig. 552). The second connects the lateral cuneiform bone with the adjacent angle of the second metatarsal bone; it does not completely divide the joint between the second metatarsal and the lateral cuneiform and is inconstant. The third connects the lateral angle of the lateral cuneiform bone with the adjacent side of the base of the fourth metatarsal bone.

Movements.—The movements permitted between the tarsal and metatarsal bones are limited to gliding of the bones upon each other. This movement is very limited in range except in the case of the joint between the medial cuneiform bone and the first metatarsal, where an appreciable amount both of up and down movement and of rotation of the metatarsal bone can be obtained passively when the muscles concerned are relaxed. These movements are carried out actively in standing and walking and form part of the mechanism by which the foot is kept plantigrade whether it is inverted or everted.

In order that the inverted foot may remain plantigrade on a flat surface, the elevation of its medial border, which is a necessary accompaniment of inversion, is corrected by medial (or downward) rotation and depression of the first metatarsal and medial cuneiform bones, brought about by the action of the peroneus longus muscle (p. 675). Conversely, in the case of eversion, the elevation of the lateral border of the foot is corrected by lateral (or upward) rotation and elevation of the first metatarsal and medial cuneiform bones, brought about passively by pressure on the ground. As a result of these movements the transverse arch of the foot (p. 545) is accentuated in inversion and flattened in eversion.

VII. THE INTERMETATARSAL JOINTS

The base of the first metatarsal bone is not connected with that of the second by any ligaments; in this respect the great toe resembles the thumb. A small bursa is often interposed between the lateral side of the base of the first metatarsal bone and the medial side of the shaft of the second (fig. 552).

The bases of the second, third, fourth, and fifth metatarsal bones are connected by dorsal, plantar, and interosseous ligaments.

The heads of all the metatarsal bones are connected indirectly by the deep transverse ligaments of the sole (p. 542).

The **dorsal and plantar ligaments** pass transversely between the bases of the adjacent bones.

The **interosseous ligaments** consist of strong transverse fibres which connect the rough non-articular portions of the adjacent surfaces (fig. 552).

Movements.—The movements permitted between the tarsal ends of the metatarsal bones are limited to a slight gliding of the articular surfaces one upon another when the anterior part of the foot is working under load (*cf.* movements of the intercuneiform joints, etc., p. 540).

THE SYNOVIAL CAVITIES OF THE TARSUS AND METATARSUS

The **synovial cavities** (fig. 552) present in the joints of the tarsus and metatarsus are six in number: one for the subtalar; a second for the talocalcaneonavicular; a third for the calcaneocuboid; a fourth for the cuneonavicular, intercuneiform, and cuneocuboid articulations, the articulations of the intermediate and lateral cuneiform bones with the bases of the second and third metatarsal bones, and the adjacent surfaces of the bases of the second, third, and fourth metatarsal bones; a fifth for the medial cuneiform bone with the metatarsal bone of the great toe; and a sixth, for the articulation of the cuboid bone with the fourth and fifth metatarsal bones. A small synovial cavity is sometimes found between the contiguous surfaces of the navicular and cuboid bones; it usually communicates with that between the cuboid and lateral cuneiform bones.

VIII. THE METATARSOPHALANGEAL JOINTS

The metatarsophalangeal joints are of the condyloid variety and are formed by the reception of the rounded heads of the metatarsal bones in shallow cavities on the bases of the proximal phalanges. They lie 2.5 cm. proximal to the webs of the toes.

The **articular surfaces** cover the distal and plantar surfaces of the heads of the metatarsal bones but do not extend on to their dorsal surfaces. The plantar part of the head of the first metatarsal presents two longitudinal grooves separated by an intervening ridge. Each groove articulates with a sesamoid bone embedded in the plantar ligament of the joint. The articular surface of the base of the proximal phalanx is concave in all diameters.

The ligaments of the joint are the fibrous capsules, plantar, deep transverse metatarsal and collateral.

The **fibrous capsules** surround the joints and are attached to the margins of the articular surfaces. Dorsally, they are thin and may be separated from the tendons of the long extensors by small bursae: they are inseparable from the deep surfaces of the plantar and collateral ligaments.

The **plantar ligaments** are thick, dense, fibrous structures. They are placed on the plantar surfaces of the joints in the intervals between the collateral ligaments, to which they are connected; they are loosely united to the metatarsal bones, but are firmly fixed to the bases of the proximal phalanges. Their margins are continuous with the deep transverse metatarsal ligaments, and their plantar surfaces are grooved for the flexor tendons, the fibrous sheaths of which are connected to the sides of the grooves; the deep surfaces of the ligaments form parts of the articular facets for the heads of the metatarsal bones.

The **deep transverse metatarsal ligaments** consist of four short, wide, flattened bands which connect the plantar ligaments of adjoining metatarsophalangeal joints to one another. Their dorsal surfaces are related to the interosseous muscles and their plantar aspects to the lumbricals and the digital vessels and nerves. They correspond closely to the deep transverse metacarpal ligaments (p. 503), but, in addition, they are connected to the plantar ligament of the first metatarsophalangeal joint.

The **collateral ligaments** are two strong, rounded cords, placed on the sides of the joints; each is attached by one end to the dorsal tubercle on the side of the head of the metatarsal bone, and runs obliquely forwards and downwards to reach the corresponding side of the base of the phalanx.

Movements.—The active movements possible at the metatarsophalangeal joints are very similar to those permitted at the corresponding joints in the hand but differ in their range. In marked contrast to the condition in the hand, the range of extension is greater than the range of flexion, and this is associated with the requirements of walking. This is especially the case in the metatarsophalangeal joint of the great toe, where flexion is limited to a few degrees but extension may be possible up to ninety degrees. In this connexion it should be remembered that when the foot is on the ground the metatarsophalangeal joints are already extended to rather more than twenty-five degrees owing to the participation of the metatarsal bones in the

longitudinal arches of the foot (figs. 553 and 554). Adduction is associated with flexion and abduction with extension, except that abduction of the little toe is always associated with a slight degree of flexion. As in the hand, the *accessory movements* comprise gliding movements and rotation of the phalanges around their long axes.

Muscles producing the movements.—In **flexion**, the *flexor digitorum brevis*, the *lumbricals* and the *interossei* are the active agents, assisted by the *flexor digitorum longus* and the *accessorius*. In the case of the little toe the *flexor digiti minimi brevis* assists, and in the case of the great toe the *flexores hallucis longus et brevis* are the only muscles concerned.

In **extension**, the *extensores digitorum longus et brevis* and the *extensor hallucis longus* are the only active agents.

In **adduction** and **abduction**, the line of reference passes through the second toe. The great toe is adducted by the *adductor hallucis*, and abducted by the *abductor hallucis*. The second toe is abducted to the medial side by the first dorsal interosseous muscle, and to the lateral side by the second. The third and fourth toes are abducted by the corresponding dorsal interossei and adducted by the first and second plantar interossei, respectively. The little toe is abducted by the *abductor digiti minimi* and adducted by the third plantar interosseous muscle.

IX. THE INTERPHALANGEAL JOINTS (DIGITAL)

The interphalangeal joints are hinge joints, and each has an articular capsule and two collateral ligaments. The arrangement of these ligaments is similar to that in the metatarsophalangeal joints (p. 542). The plantar surface of the articular capsule is strengthened to form a fibrous plate, similar to the plantar metatarsophalangeal ligament. This is often termed the *plantar ligament*.

Movements.—The only active movements permitted in the joints of the digits are flexion and extension; these movements are freer between the proximal and middle phalanges than between the middle and distal. The amount of flexion is very considerable, but extension is limited by the tension of the flexor muscles and by the plantar ligaments.

The *accessory movements* comprise abduction, adduction and rotation.

Muscles producing the movements:

Flexion.—*Flexores digitorum longus, brevis et accessorius, flexor hallucis longus.*

Extension.—*Extensor hallucis longus, extensores digitorum, longus et brevis.*

THE MOVEMENTS OF THE FOOT AS A WHOLE

The movements of the foot may take place either when the foot is off the ground and free to move on the leg or when it is on the ground and bearing weight. In the latter case the movements are more limited in range and they may be imposed on the foot by the body-weight acting through the femur, tibia and talus, or they may be the result of the active contraction of muscles acting on the foot.

When the foot is off the ground, active movements may occur at the talocrural and at the talocalcaneonavicular and subtalar joints. At the talocrural joint the movements are restricted to dorsiflexion and plantar flexion. At the talocalcaneonavicular and subtalar joints, inversion and eversion of the foot occur, these movements being accompanied by a limited amount of rotation around a vertical axis with the result that the inverted foot is rotated medially and the everted foot is rotated laterally.

When the foot is on the ground and bearing weight in the resting position, the body-weight, acting through the femur, tibia and talus, thrusts it into the everted position and flattens the transverse arch. In the process the first metatarsal bone is pressed upwards with the result that the foot, although everted, can remain plantigrade. At the same time the longitudinal arch of the foot is flattened, though a part of this flattening is more apparent than real and is due to the fact that the foot is rolled over to the medial side at the talocalcaneonavicular and subtalar joints. When the position of rest is changed to the active position, e.g. on commencing to walk, the foot becomes inverted and the longitudinal arch assumes its maximum height. This alteration is brought about by the active contraction of the *tibialis anterior* (p. 672) and the *tibialis posterior* muscles (p. 682), while the simultaneous contraction of the *peroneus longus* accentuates the transverse arch, depressing the first metatarsal bone and so ensuring that the foot remains plantigrade in the position of inversion.

Similar movements can be imposed on the weight-bearing foot by active rotation of the femur. Lateral rotation of the femur is transmitted through the tibia to the talus and the foot becomes inverted passively at the talocalcaneonavicular and subtalar joints. Medial rotation of the femur has the opposite effect.

THE ARCHES OF THE FOOT

The foot has two important functions to perform. (1) It must support the weight of the body in standing. (2) It must act as a lever to propel the body forwards in walking.

To fulfil the first function perfectly, the foot should lie flat on the ground and should be pliable enough to adapt itself to uneven surfaces. In actual fact, the foot of the child approaches this ideal much more nearly than the foot of the adult, which is, to a certain extent, permanently arched.

FIG. 553.—The skeleton of the left foot. Medial aspect. Note the height of the medial part of the longitudinal arch and compare with fig. 554.

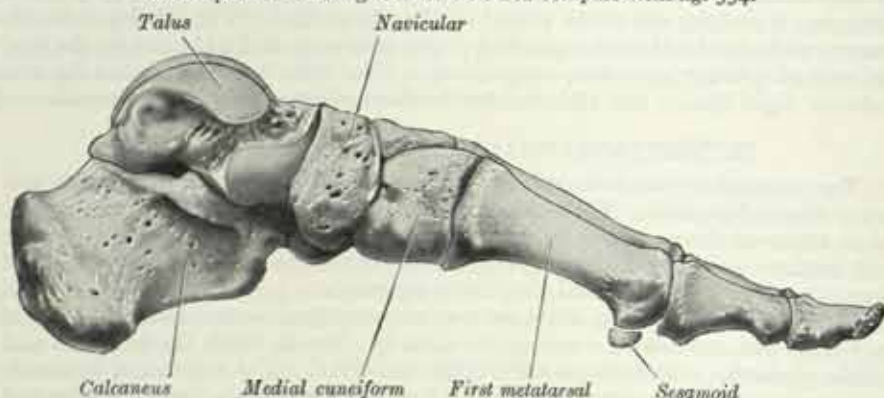
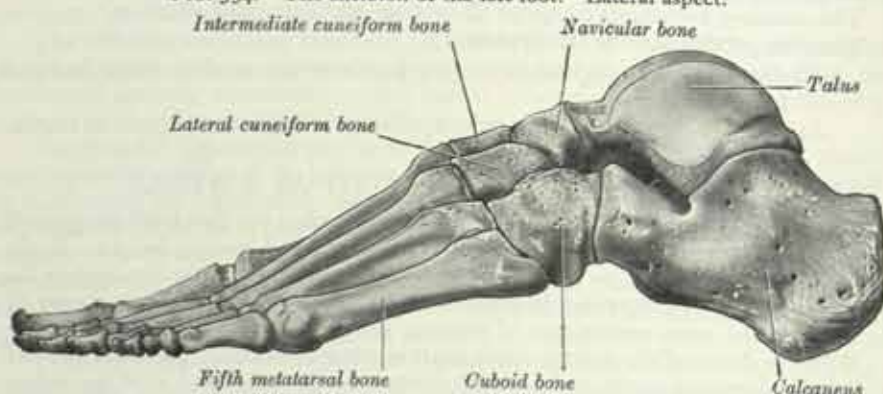


FIG. 554.—The skeleton of the left foot. Lateral aspect.



To fulfil its second function the foot must be capable of transformation into a rigid lever which will not collapse under the body-weight. A segmented lever, such as the foot, can only withstand stress if it is built up into an arch form, and in active use, therefore, the muscles acting on the foot convert it into a complex but rigid, arched lever. The arches thus formed comprise a longitudinal arch, which is divisible into a medial and a lateral portion, and a transverse arch. In the average adult these arches do not flatten out completely when the muscles are relaxed, and they are therefore to that extent permanent. They vary in height in different subjects.

The *medial arch* (fig. 553) is made up of the calcaneus, the talus, the navicular, the three cuneiform bones, and the first, second and third metatarsals. Its summit is at the superior articular surface of the talus, and its two extremities or piers, on which it rests in the erect posture, are the tubercles on the plantar surface of the calcaneus posteriorly, and the heads of the first, second and third metatarsal bones anteriorly. The chief characteristic of this arch is its resilience, due to its height and to the number of joints between its component parts. The arch is dependent for its maintenance on the tibialis posterior, the flexor digitorum longus, the flexor hallucis longus and the small muscles in the sole of the foot. Flattening of the arch

is resisted by the tension of these muscles and by the plantar aponeurosis and the plantar ligaments of all the joints concerned, including the plantar calcaneonavicular or 'spring' ligament (p. 539).

The *lateral arch* (fig. 554) is composed of the calcaneus, the cuboid, and the fourth and fifth metatarsal bones. Its summit is at the subtalar articulation, and its chief joint is the calcaneocuboid, which allows only a limited range of movement. The most marked features of this arch are its solidity and its slight elevation; it is supported by the peroneus longus and the short muscles of the little toe, and its integrity is preserved by the long plantar and plantar calcaneocuboid ligaments.

In addition to the longitudinal arches the foot presents a series of *transverse arches*. At the posterior part of the metatarsus and the anterior part of the tarsus the arches are complete, but in the middle of the tarsus they present more the characters of half-domes the concavities of which are directed downwards and medially, so that when the medial borders of the feet are placed in apposition a complete tarsal dome is formed. The transverse arches are supported by the short muscles of the first and fifth toes (especially the transverse head of the adductor hallucis), and by the peroneus longus, the tendon of which stretches between the piers of the arches; they are strengthened by the interosseous and plantar ligaments.

It should be observed that in a normal foot the arches become flattened when the erect posture is assumed, and are restored when the weight of the body is taken off the feet. This resilience accounts for the suppleness of the normal foot and enhances the value of the arches by rendering possible such rapid and sudden movements as running and jumping.

In the resting upright posture the feet take up the position of eversion, but the first metatarsal and medial cuneiform bones are elevated and rotated upwards relative to the rest of the foot (p. 541). The latter movement is essential to allow the lateral border of the everted foot to remain in contact with the ground, and it results in a flattening of the transverse arch of the foot. The medial longitudinal arch appears to be more flattened than can be accounted for by the elevation of the first metatarsal bone. This is due to the fact that in eversion the arch rolls over, as it were, to the medial side, so that its concavity faces laterally and downwards instead of directly downwards.

When the posture is changed from the position of rest to one of activity, the foot becomes slightly inverted, the medial longitudinal arch is both apparently and actually raised and the transverse arch is accentuated by the action of the peroneus longus (p. 675). In this position the foot functions as an almost rigid but yet slightly resilient lever, as the full value of both arches can be utilised.

It should be observed that when the foot is on the ground it is not free to move round the talus in the movements of eversion and inversion, and these movements are brought about, in large part if not entirely, by a twisting of the talus on the rest of the foot. This twisting is the result of rotation of the lower limb, either at the knee or at the hip-joint, and is transmitted to the talus through the tibiofibular mortise.

Applied Anatomy.—In young children the foot appears to be completely flat in the resting upright posture, owing to the fact that it is everted at the subtalar joints and supinated at the first cuneometatarsal and cuneonavicular joints; during activity, however, the arched form of the foot at once becomes apparent. In most adults, on the other hand, the foot does not flatten completely in the resting upright posture, for, with increase of age, the arches become to some extent permanent structures. In some adults—particularly those with long and narrow feet—the foot appears to be abnormally flat in the resting posture, but the arches become apparent during activity. The functions of the foot are not impaired, but, despite this fact, these cases are often described as exhibiting a 'first-degree flat foot'.

There are two varieties of flat foot associated with marked impairment of function. In the first the flat, everted position assumed during rest persists when the resting posture is changed to one of activity, although the foot can still assume a normal arched form when not bearing weight. In this variety the deformity is purely postural and is due to loss of muscle tone and lack of muscular co-ordination. It is commonly associated with pain which is due to stretching of the plantar ligaments of the joints of the foot. The condition is often a local manifestation of a general postural deficiency, and its cure therefore depends upon correction of bad postural habits and re-education of the muscles.

In the second variety the flat, everted position of the foot becomes fixed as a result either of persistent muscle spasm or of joint stiffness following some inflammatory process. Such cases are described as 'rigid flat foot', as the arched form of the foot cannot be produced even by passive movements.

MYOLOGY

MUSCULAR tissue is known to the layman as 'flesh', and it is most familiar to him as the lean parts of a joint of meat. There are three varieties of muscular tissue: (1) *striped* or *voluntary*, (2) *unstriped* or *plain*, and (3) *cardiac*. The microscopical characters of these three varieties have been described in a previous section (pp. 31 to 37). This section deals only with voluntary muscle.

The individual fibres of voluntary muscle with their sheaths of *sarcolemma* (p. 32) are bound together into bundles or fasciculi by a connective tissue covering, termed the *perimysium*. Groups of fasciculi are in turn bound together by a similar but denser covering, termed the *epimysium*, and these groups form the individual *voluntary muscles* of the body. The voluntary muscles of the eyeball, ear, tongue, palate, larynx and pharynx are considered with the anatomy of the organs concerned, but all the other voluntary muscles of the body will be included in this section.

All muscular tissue possesses the property of contractility, and movements of the body as a whole or of any of its parts are effected by the active contraction of a group or groups of voluntary muscles.

Types of muscle fibres.—Many bivalves are provided with two distinct types of voluntary muscle. The one consists of pale fibres, which are capable of rapid contraction and have a high metabolic rate. They come into play to effect the closure of the shell. The other type consists of dark, red fibres, which contract more slowly and have a lower metabolic rate. In these fibres the nuclei tend to be placed more centrally and their structure is rather more primitive. Their function is to keep the shell closed. In man and other vertebrates both pale and red fibres are present in all the voluntary muscles, but in varying proportions. It has been estimated that in some muscles, e.g. the *Gastrocnemius*, the pale fibres predominate, while in others, e.g. the *Soleus*, the red fibres are in the majority, and it has been suggested that the former are mainly concerned with the initiation and performance of movements, while the latter are mainly concerned with the determination and maintenance of posture. Speaking broadly, red fibres are present in relatively greater numbers in anti-gravity muscles, which for the most part are extensor muscles. In this connexion it is interesting to note that in the *Quadriceps* extensor muscle group of the thigh (p. 658) the *Vastus lateralis* has been shown to possess a relatively high content of red fibres,* although the *Vastus medialis* is composed largely of pale fibres. This would appear to suggest that a high proportion of red fibres in one constituent muscle of a group is sufficient to cover the requirements of postural movements and maintenance.

Attachments.—In order that a muscle may exercise its function of producing movements, it must be attached at both of its extremities. When a muscle contracts, one of its attachments remains relatively stationary, while the other is approximated to it. The term *origin* is used to designate the more fixed attachment and the term *insertion* to designate the movable point at which the force of the muscle is applied. As a general rule, so far as the limbs are concerned, the origin is the more proximal extremity of a muscle and the insertion the more distal. In accordance with these definitions the contraction of a muscle results in the approximation of its insertion to its origin, but the terms are arbitrary and used for convenience only, and it frequently happens that the contraction of a muscle may result in the approximation of its origin to its insertion. The *Gluteus maximus* provides an illustration of this fact. When it assists in extending the flexed thigh, its insertion into the gluteal tuberosity of the femur is then approximated to its origin from the dorsal surface of the sacrum. On the other hand, when the body is bent forwards at the hips, the *Glutei maximi* assist in restoring it to the erect posture and, in this movement, the origin is approximated to the insertion.

The voluntary muscles are attached to the bones, cartilages, ligaments, skin or to other muscles, either directly or through the medium of fibrous structures called

* Denny-Brown, D. E., *Proc. Roy. Soc.*, 104, B, 1929.

tendons and aponeuroses. Where a muscle is attached directly to bone or cartilage, the perimysium blends with the periosteum or perichondrium so that the fleshy fibres do not actually come into direct relation with the osseous or cartilaginous tissue, although they may appear to do so. Where muscle fibres are inserted into skin, e.g. the muscles of facial expression, they lie as a flattened layer on its deep surface and their perimysium blends with the subcutaneous areolar tissue. It may be noted that in such cases the insertion is incapable of becoming the fixed point, so that contraction always approximates the insertion to the bony origin.

Most muscles are provided with tendons at one or both extremities. *Tendons* are known to the layman as 'sinews' or 'leaders'; they consist of white fibrous tissue (p. 14) and are usually cord- or band-like in appearance. In flat, sheet-like muscles, which have a wide area of attachment a relatively thin but strong fibrous sheet takes the place of a cord-like tendon and is termed an *aponeurosis*. Where no tendon or aponeurosis can be seen with the naked eye, the attachment appears to be fleshy in character, but, as already stated, it is actually effected through the medium of the fusion of the perimysium with the periosteum or perichondrium.

Where one muscle is attached to another, the character of the connexion may be fleshy, tendinous or aponeurotic. (1) The fleshy fibres may interlace, e.g. the mylohyoid muscles, and the perimysium of the one fuses with the perimysium of the other. (2) The two muscles may be connected by a common tendon. Such muscles are termed digastric and the two fleshy bellies are usually set at an angle which is maintained by a fascial loop thrown round the tendon from an adjoining bony point. (3) The two muscles may be connected by the interlacement of the fibres in their aponeuroses, e.g. the muscles of the abdominal wall.

Attachments of muscles exert a definite influence in the modelling of the bones of the skeleton and, when the attachment is tendinous in character, localised, elevated areas are usually present. On the other hand, when the muscle is attached by fleshy fibres the bony surface is smooth, and shows no corresponding elevations.

The muscles of the limbs with very few exceptions are inserted immediately distal to the joint on which they exert their principal action. This arrangement implies a loss of mechanical advantage, but what is lost in power is gained in the speed with which the hand or the foot, as the case may be, is moved over a wide range. For example, when the Brachialis muscle contracts, its insertion into the coronoid process of the ulna moves round an arc of a circle with a very short radius, but in the same period of time the hand moves round the corresponding arc of a circle whose radius is the length of the forearm and hand.

Muscular form.—The *form* of a muscle depends on the number and arrangement of its constituent fibres. When the fibres are arranged parallel or nearly parallel to what may be termed the 'line of pull' of the muscle, the full advantage of the muscular contractility is available and the maximum range is obtained. Such muscles may be *quadrilateral*, like the Thyrohyoid; *fusiform*, like the Flexor carpi radialis; or *straplike*, such as the Sartorius. If, on the other hand, the fibres are arranged obliquely in relation to the 'line of pull', the range is diminished, for the force of the muscular action can then be resolved into two components, one acting in the 'line of pull' and the other at right angles to it and therefore valueless so far as the range of the muscle is concerned. This oblique arrangement of the fibres is seen (a) in *unipennate* muscles such as the Flexor pollicis longus, in which the tendon of insertion extends upwards along one border of the muscle, (b) in *bipennate* muscles, such as the Rectus femoris, where the tendon extends upwards through the middle of the muscle, and (c) in *multipennate* muscles, such as the Deltoid, where a number of extensions pass upwards into the muscle from its tendon of insertion. The same arrangement is seen (d) in *triangular* muscles, such as the Temporalis, in which the muscular fibres converge on an apical tendon. As a rule the various forms of pennate and triangular muscles contain a larger number of fibres than fusiform, quadrilateral or straplike muscles, and they are found in situations where increased power is essential, because *the power of a muscle is directly proportional to the number of its constituent fibres*.

Muscular contraction.—When a muscle is called on to participate actively in the production of a movement, all of its fibres are not necessarily thrown into contraction, for it adapts itself to the work which it is required to perform, and the

more vigorous the effort demanded, the greater the number of fibres involved. The contraction of any individual fibre is always maximal, and this is often referred to as the 'all or none' principle of muscle contraction. During contraction a muscle fibre may shorten by thirty to forty per cent. of its uncontracted length.* As all the fibres in a given muscle are attached by one end to the tendon of origin, or its prolongation into the muscle, and by the other to the tendon of insertion, the maximum amount of shortening of the muscle is equal to the maximum amount of shortening of any one fibre, provided that all the fibres in the muscle are uniform in length, e.g. Sartorius. Owing to the rigidity of the bones, the amount of shortening possible is only a small percentage of the distance between the origin and the insertion, and the length of muscle fibres is adapted to their requirements. When, therefore, the muscle fibres are arranged parallel to the 'line of pull', the muscular belly may be relatively short, and it is then provided with a long tendon—an arrangement which is both economical and efficient, for muscle tissue has a high metabolic rate and white fibrous tissue a low one.

Muscular actions.—Theoretically a muscle is capable of acting on every joint over which it passes, and the particular movements in which it takes part depend on the relationship of its 'line of pull' to the axes of the movements of the joint. For example, a muscle which passes in front of the transverse axis of the shoulder joint will take part in the movement of flexion and, if it passes below the joint, it will also take part in adduction. It is movements, however, and not individual muscles which are represented in the cerebral cortex and it does not follow that a muscle will participate in a given movement because the mechanics of its attachments enable it to do so.

When a movement is carried out, a definite combination of muscles is called into play, and no muscle can be omitted nor can one be added, voluntarily. One muscle or more of the combination is the *prime mover*, and its active contraction necessarily involves the relaxation of its *antagonist*. The full effect, however, of the contraction of a prime mover can be obtained only when one of its attachments (usually the origin) is fixed; therefore, in the case of limb movements, every contraction of the prime movers is accompanied by the contraction of groups of *fixation muscles*. For example, the Deltoid is the prime mover in abduction of the arm and it can exert its full effect only when its clavicular and scapular origins are fixed. As a result abduction of the arm is always accompanied by contraction of muscles inserted into the scapula; and they are the fixation muscles for that movement.

Many muscles, if acting unassisted, would fail to develop their full efficiency on account of the physical possibility of the occurrence of subsidiary harmful or hampering movements. This is particularly the case when a muscle passes over several joints before it reaches its insertion, but it occurs also in cases where only a single joint is involved, particularly when the joint is mechanically unstable. The prevention of such harmful or hampering movements is effected by the contraction, or increased tonus, of other muscles, which are described as *synergic* in this connexion. For example, when the fist is clenched, the prime movers are the flexors of the fingers, the flexors and adductor of the thumb and the Opponens pollicis muscle. The long flexors pass in front of the wrist joint and are able to flex that joint, but only at the expense of the power with which they act on the digits. The extensors of the wrist, which are the synergic muscles for the movement, are therefore thrown into contraction in order to steady the wrist and obviate this loss of power.

The instability of the shoulder joint calls for the constant activity of synergic muscles during free use of the arm. In the initial stage of abduction the tendency of the head of the humerus to glide upwards in the glenoid cavity under the pull of the deltoid muscle is counteracted by the synergic action of the Subscapularis, Infraspinatus and Teres minor muscles, which exert downward traction on the head of the bone (p. 487). In the same way, when the arm is raised from the side, the tendency of the head of the humerus to skid backwards is counteracted by the synergic action of the Subscapularis, which steadies and controls the head, retaining it in its correct relationship to the glenoid cavity. It should be observed, however, that there is no essential difference between fixation and synergic muscles, in so

* According to R. W. Haines, *J. Anat., Lond.*, **69**, 1934, muscle fibres normally contract to 57 per cent. of their length when relaxed and fully stretched, but R. W. Ramsey and S. F. Street, *J. cell. comp. Physiol.*, **15**, 1940, claim that contraction to less than 70 per cent. of the resting length, may result in permanent shortening and structural change.

far as they both prevent waste of power and loss of efficiency on the part of the prime movers.

Under certain conditions the muscular groups which are called into play for some movements are profoundly altered by the action of gravity. When the body is in the erect posture flexion of the trunk is initiated by the ventral muscles, but thereafter the movement is carried out by the action of gravity, controlled and regulated by the *Erectores spinæ*. The abducted arm is brought down to the side in a similar manner. In this instance the action of gravity is controlled by the Deltoid muscle, and the adductor muscles do not participate in the movement unless resistance is encountered.

It will now be apparent that the efficient performance of any movement depends on the proper co-ordination of prime movers, antagonists and fixation and synergic muscles, and this co-ordination is ensured by the manifold connexions which exist within the central nervous system.

Muscle tonus.—When normally innervated living striated muscle is stretched it pulls back against the extending force and active resistance is encountered. Sherrington showed that the active resistance depended on a reflex arc involving the sensory organs in muscle (muscle spindles) and the nerve ending in tendons which respond to stretch and therefore are termed stretch receptors (see p. 921), afferent fibres to the spinal medulla, and efferent (motor) fibres to the muscle undergoing stretch. He also showed that the active resistance (stretch reflex) could be divided into two parts, firstly a phasic (fast) component to sudden stretch and secondly a static (slow component) to maintained stretch. Sherrington suggested that wherever a muscle *in vivo* was extended a stretch reflex would be initiated tending to produce reflex motor unit activity in the same muscle. This reflex motor unit activity was called muscle tonus or tone.

Clinicians also use the term muscle tone to signify the resistance due to muscles encountered during the passive manipulation of a limb. This resistance is a measure of the static component of the stretch reflex, while eliciting a tendon reflex measures the phasic component.

Electromyography has demonstrated that a normally innervated striated muscle at rest exhibits no motor unit activity although its stretch reflex and tonus may be normal. Muscle tonus may conveniently therefore be defined as the sensitivity to the static component of the stretch reflex. A muscle may thus be said to possess tone even at times when it exhibits no motor unit activity. Variations in muscle tonus thus defined may result from alteration of activity of the muscle fibres concerned in the muscle spindles (see pp. 925-926).

Muscle tonus is of great importance in the maintenance of posture and for the maintenance of a continued state of preparedness of the muscles for action. Muscle tonus is lost if the spinal medulla is destroyed or if the motor or sensory nerves to the muscle are severed.

Blood-supply.—The blood-supply of muscles is derived from the muscular branches of neighbouring arteries. In many muscles the branches of the principal artery and of the nerve of supply enter together along a line which is often termed the *neurovascular hilum*. This is more or less constant in position. Subsidiary arteries are generally present and enter at the periphery or close to the ends of the muscle. Within the muscle the blood vessels anastomose and terminate in a fine network of capillaries around the muscle fibres. The size and number of independent arteries and the manner and efficiency of their anastomoses vary with the individual muscles.*

Nerve-supply.—Each voluntary muscle receives one or more motor nerves of supply. In the cases of the limb muscles and the muscles of the face, head and neck the nerve-supply is usually single, but where a muscle retains its segmental arrangement (e.g. the muscles of the abdominal wall), its nerve-supply is multiple. As a rule, after dividing into several small branches, the nerve of supply enters the deep surface of the muscle not far from its origin and then forms an intramuscular plexus. The site of entry of the nerve is fairly constant for each individual muscle. Each of the fibres derived from the intramuscular plexus innervates a large number of muscle fibres (p. 926) through terminals which lose their myelin sheaths when they pierce the sarcolemma to end in a *motor end-plate* (p. 926). In addition, most

* J. C. Brush, *Neuro-vascular Hila of Limb Muscles*. Livingstone, Edinburgh and London, 1955.

muscles also possess a sensory nerve-supply. These afferent fibres run in the same nerve-trunk as the motor fibres and convey proprioceptive impulses, being most numerous in muscles primarily concerned with posture. Their terminals are associated with *neurotendinous endings* and *neuromuscular spindles* (p. 925).

Reciprocal Innervation of Muscles.—It has already been stated that the contraction of a group of prime movers is, under normal circumstances, always accompanied by a corresponding degree of relaxation of the appropriate antagonists. This constitutes the 'principle of reciprocal innervation'. The connexions in the central nervous system which provide the pathways concerned are available not only in the spinal medulla but also at higher levels, including the cerebral cortex. It appears that an afferent to the spinal medulla—irrespective of the character of the stimulus which it conveys—can at the same time evoke activity of a motor (say, flexor) unit and relaxation of a corresponding antagonistic (extensor) unit. It is true that by voluntary effort both prime movers and their antagonists can be thrown into contraction simultaneously. This possibility does not vitiate the principle of reciprocal innervation but must be regarded as an instance of the dominant part which the cerebral cortex can play in muscular control.

THE TENDONS, APONEUROSES AND FASCIAE

The **tendons** are tough, whitish cords, varying in length and thickness, and devoid of elasticity. They consist of numerous parallel fascicles of collagen fibres and their parent cells, surrounded by fibro-areolar tissue which binds them all together and constitutes the interfascicular tissue. Where the tendon leaves the muscle, its interfascicular tissue is continuous with the perimysium of a group of muscle fibres, and the sarcolemmal sheaths of the fibres are continued as collagen bundles. Where the tendon reaches its attachment to bone, the interfascicular tissue blends with the periosteum, but the collagenous fibres pass through the cortical bone as the perforating fibres of Sharpey (p. 25).*

The blood-supply of the tendon cells and the interfascicular tissue is derived from a number of longitudinally running small arterioles which are continued down from the perimysium and course for the most part in the interfascicular grooves. These little vessels communicate freely with one another and each is accompanied by two *venae comitantes* and four lymphatic vessels. In situations where the tendons are running free and are not provided with synovial sheaths, they are surrounded by loose fatty areolar tissue through which the neighbouring vessels communicate with, and reinforce, the interfascicular vessels. Where the tendons are enclosed in synovial sheaths, small vessels traverse the vincula and link up with the interfascicular vessels and with the vessels running in the synovial covering of the tendon.

So far as is known, these vessels are restricted in their distribution to the tendon cells and the interfascicular tissue. The collagenous fascicles, here as elsewhere in the body, have a low metabolic rate and constitute one of the most economic of all the tissues.

Nerves supplying tendons end in what are known as *neurotendinous endings* of Golgi; these are described with the organs of the senses.

The **aponeuroses** are flattened or expanded sheets of white fibrous tissue, of a pearly-white colour, iridescent and often glistening; they are only sparingly supplied with blood-vessels.

The tendons and aponeuroses connect the muscles with the structures to be moved, such as the bones and cartilages. Where the end of a muscle is continued directly into a tendon, the line of junction between the two is usually well-defined, but where the muscle meets the tendon obliquely, bundles of tendon fibres generally run for a variable distance into the substance of the muscle, so that the line of junction is irregular. Microscopic examination shows that, in either case, the tendon is subdivided into small bundles, corresponding in size and number with the fibres of the muscle. Each muscular fibre ends in a more or less rounded extremity covered with sarcolemma, and the fibres of each tendon bundle are intimately united with the sarcolemma covering the end of the muscular fibre. The mode of union is well shown when the muscle fibre has shrunk inside its sarcolemma.

* D. A. W. Edwards, *J. Anat., Lond.*, **80**, 1946.

In situations where a muscle has to bend round a bony point to reach its insertion the fleshy fibres cease before the change of direction begins so that the part subjected to pressure at the bend is tendinous in character. Friction is obviated by the provision of a synovial sheath or bursa (see below).

The *fasciæ* are fibro-areolar, membranous laminæ, of variable thickness and strength, found in all regions of the body, investing the softer and more delicate organs. During the process of development many of the cells of the mesoderm are differentiated into bones, muscles, vessels, etc.; the cells of the mesoderm which are not so utilised form an investment for these structures and are differentiated into the true skin and the *fasciæ* of the body. The *fasciæ* are subdivided into superficial and deep.

The *superficial fascia* is found immediately beneath the skin over the entire surface of the body. It connects the skin to the subjacent parts, and consists of fibro-areolar tissue, containing in its meshes pellets of fat in varying quantity. It varies in thickness in different parts of the body and is thicker and more evenly distributed in women than in men. It facilitates the movement of the skin, serves as a soft bed for the passage of vessels and nerves to the skin, and retains the warmth of the body, since fat is a bad conductor of heat. In the groin, especially in fat subjects, it may be subdivided into several laminæ. Beneath the fatty layer there is generally another layer of superficial fascia, almost devoid of adipose tissue, in which the trunks of the subcutaneous vessels and nerves and the superficial lymph-glands are found. Certain cutaneous muscles are situated in the superficial fascia, e.g. the *Platysma* and the muscles of the face. The superficial fascia is most distinct at the lower part of the abdomen, where it contains numerous yellow elastic fibres, in the perineum, and in the limbs; it is very thin on the dorsal aspects of the hands and feet, on the side of the neck, in the face, and around the anus. It is very dense in the scalp, palms of the hands, and soles of the feet, forming a fibro-fatty layer which binds the skin firmly to the underlying structures.

The *deep fascia* is a dense, inelastic membrane, forming sheaths for the muscles, and in some cases affording them broad surfaces for attachment. It consists of bundles of white fibrous tissue, placed parallel with one another and connected together by other fibres disposed in a rectilinear manner. It forms a strong investment which not only binds down collectively the muscles in each region, but may give a separate sheath to each, and to the vessels and nerves as well. It assists the muscles in their actions by the degree of tension and pressure it makes upon their surfaces; in certain situations the degree of tension and pressure is regulated by muscles inserted into it, as, for instance, by the *Tensor fasciæ latæ* and *Gluteus maximus* in the thigh, and the *Palmaris longus* in the hand. In the limbs, the fascia not only invests the limb, but gives off septa which separate the various muscles, and are attached to the periosteum: these prolongations of *fasciæ* are usually spoken of as *intermuscular septa*.

In some situations the deep fascia shows a localised thickening, consisting largely of transversely running fibres. These are termed *retinacula* and they form retaining bands in the neighbourhood of the wrist and ankle joints to hold down the tendons. They are attached to the adjoining bony prominences and they help to form osteofibrous canals through which the tendons pass. When the muscles concerned contract vigorously, and bring about movements of the hand or foot, the tendons pull against the *retinacula*, which function as pulleys and serve to prevent loss of power. Synovial sheaths are provided for the tendons in these situations in order to obviate friction.

Similar fascial thickenings occur in the palm of the hand and the sole of the foot and on the flexor surfaces of the digits. In the first two situations, in addition to exercising a restraining effect on the tendons, they have a protective function.

Synovial bursæ and sheaths.—In certain situations where friction is likely to occur, e.g. where a tendon twists round a bone or where a subcutaneous bony point is liable to pressure, a definite sac is formed in the interposed fibro-areolar tissue, the walls of which are identical in structure with the synovial membrane of synovial joints (p. 454). These sacs are termed *synovial bursæ*. The *synovial sheaths*, which are associated with many of the tendons and will be described individually with them, have a similar structure.

THE FASCIAE AND MUSCLES OF THE HEAD

I. THE MUSCLES OF FACIAL EXPRESSION

(A) *The Muscle of the Scalp*—Epicranius

The Epicranius consists of two main parts :

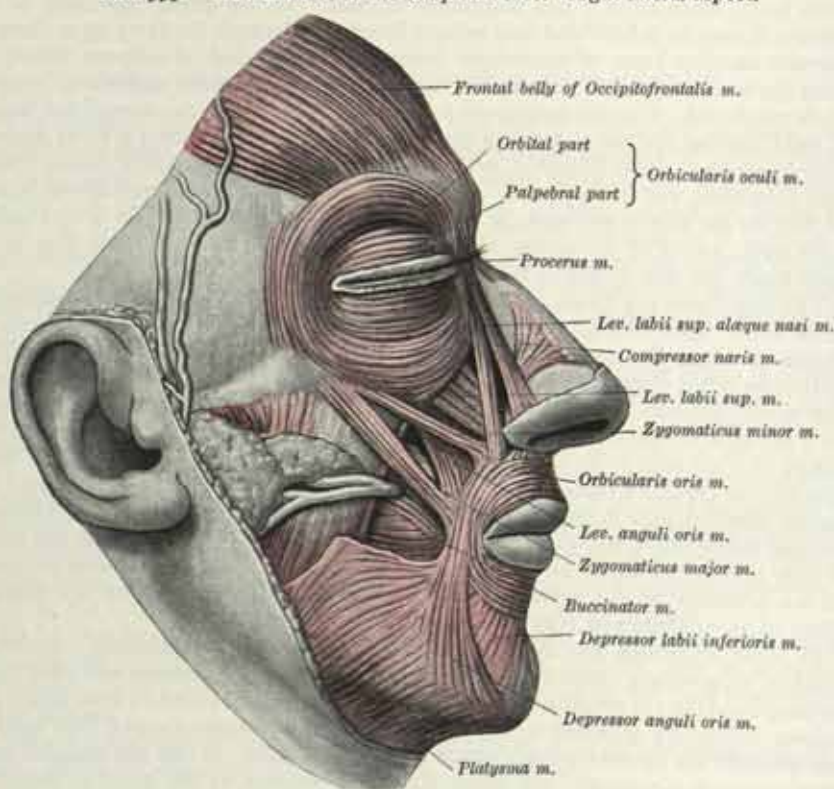
Occipitofrontalis

Temporoparietalis

The **superficial fascia** in the scalp is a firm, fibro-fatty layer, intimately adherent to the skin, and to the underlying Epicranius muscle and its aponeurosis, the galea aponeurotica ; behind, it is continuous with the superficial fascia at the back of the neck ; laterally, it is prolonged into the temporal region, where it is looser in texture.

The **Occipitofrontalis** is a broad, musculofibrous layer which covers the top of the skull, from the nuchal lines to the eyebrows. It consists of four bellies—two

FIG. 555.—The muscles of the scalp and face. Right lateral aspect.



occipital and two frontal—connected by an intervening aponeurosis, termed the galea aponeurotica.

Each *Occipital belly*, thin and quadrilateral in form, arises by tendinous fibres from the lateral two-thirds of the superior nuchal line of the occipital bone, and from the mastoid part of the temporal bone. It ends in the galea aponeurotica.

Each *Frontal belly* (fig. 555) is thin, of a quadrilateral form, and intimately adherent to the superficial fascia. It is broader than the Occipital belly and its fibres are longer and paler in colour. It has no bony attachments. Its medial fibres are continuous with those of the Procerus ; its intermediate fibres blend with the Corrugator supercilli and Orbicularis oculi ; and its lateral fibres are also blended with the latter muscle over the zygomatic process of the frontal bone. From these attachments the fibres are directed upwards, and join the galea aponeurotica in front of the coronal suture. The medial margins of the Frontal bellies are joined together for some distance above the root of the nose ; but between the Occipital bellies

there is a considerable, though variable, interval, occupied by an extension of the galea aponeurotica.

The *Temporoparietalis* is a variably developed sheet of muscle which lies between the frontal belly of the Occipitofrontalis and the anterior and superior Auricular muscles.

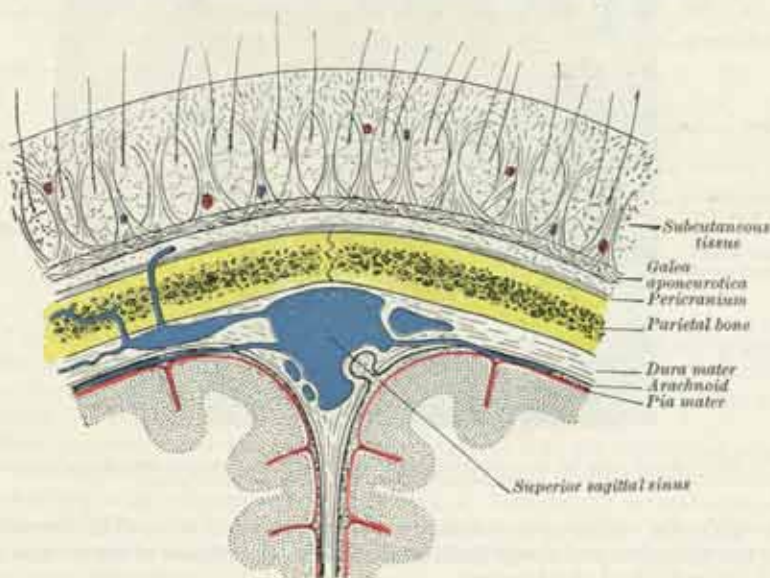
The *galea aponeurotica* (*epicranial aponeurosis*) covers the upper part of the cranium and forms with the *Epicranius* muscle a continuous fibromuscular sheet extending from the nuchal lines to the eyebrows. Behind, in the interval between the occipital bellies of the Occipitofrontalis, the galea aponeurotica is attached to the external occipital protuberance and highest nuchal line of the occipital bone. In front it splits to enclose the frontal bellies and sends a short narrow prolongation between them. On each side it gives origin to the *Auriculares anterior et superior*; in this situation it becomes thinner, and is continued over the temporal fascia to the zygomatic arch. It is closely united to the skin by the firm, fibro-fatty superficial fascia; it is connected to the pericranium by loose cellular tissue which allows of the movement of the galea aponeurotica, the latter carrying with it the skin of the scalp.

Nerve-supply.—The Occipital belly is supplied by the posterior auricular branch, and the Frontal belly by the temporal branches, of the facial nerve.

Actions.—The Occipital bellies draw the scalp backwards; the Frontal bellies acting from above raise the eyebrows and the skin over the root of the nose; acting from below they draw the scalp forwards, throwing the integument of the forehead into transverse wrinkles. The Occipital and Frontal bellies, acting alternately, move the entire scalp backwards and forwards. In the ordinary action of the Frontal bellies the eyebrows are elevated, thus giving to the face the expression of surprise; if the action be exaggerated, the eyebrows are still further raised, and the skin of the forehead thrown into transverse wrinkles, as in the expression of fright or horror.

A thin muscular slip, termed the *Transversus nuchæ*, is present in about 25 per cent. of cases; it arises from the external occipital protuberance or from the

FIG. 556.—A coronal section through the scalp and skull. Diagrammatic.



superior nuchal line, either superficial or deep to the Trapezius; it is frequently inserted with the *Auricularis posterior*, but may join the posterior edge of the *Sternomastoid*.

Applied Anatomy.—The scalp consists of five layers, viz. the skin, subcutaneous tissue, *Epicranius*, and its aponeurosis, subaponeurotic areolar tissue, and pericranium (fig. 556). But from a surgical standpoint it is better to regard the first three of these as a single layer, since they are all intimately united, and when torn off

in an accident, or turned down as a flap in a surgical operation, remain firmly connected to each other. In consequence of the dense character of the subcutaneous tissue, the amount of swelling which occurs as the result of inflammation is slight; and a wound which does not involve the Epicranius or the galea aponeurotica does not gape. The blood-vessels which lie in this tissue do not contract when wounded, and therefore the hæmorrhage from scalp wounds is often very considerable. It can, however, always be arrested by pressure—a matter of great importance, as, owing to the retraction of the cut ends, it is often very difficult or impossible to pick up with forceps a wounded vessel in the scalp.

The subaponeurotic areolar tissue is, from a surgical point of view, of considerable importance. It is loose and lax, and is easily torn through; and hence, in wounds of the scalp, it is this tissue which is torn when the flap is separated from the parts beneath. The vessels are contained in the flap, and there is little risk of sloughing, unless the vitality of the part has been actually destroyed by the injury.

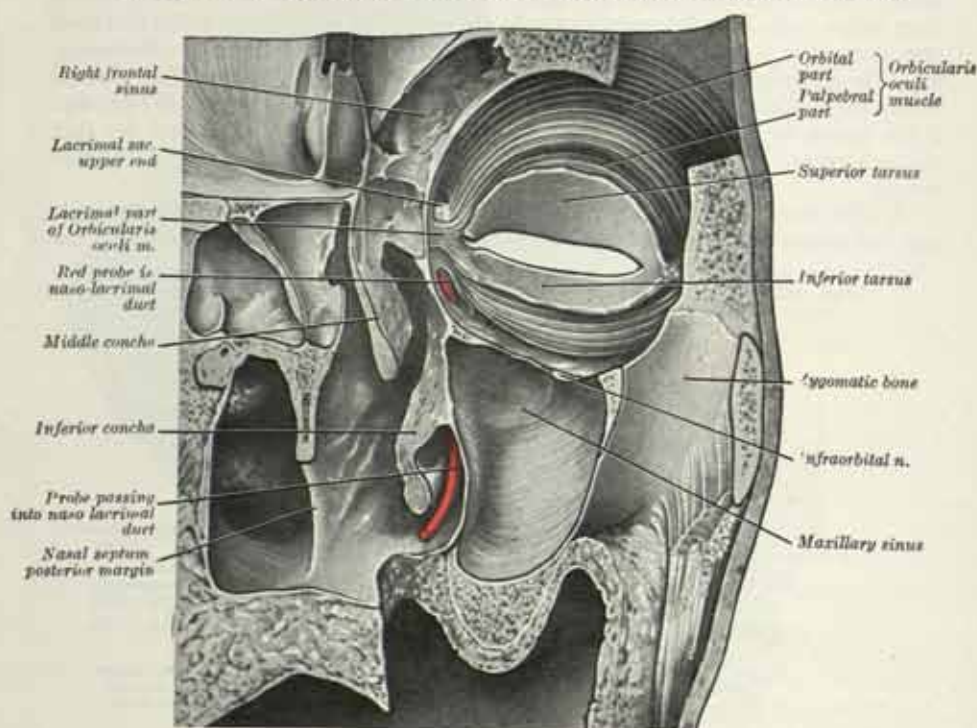
(B) The Muscles of the Eyelids

Levator palpebræ superioris. Orbicularis oculi. Corrugator supercilii

The Levator palpebræ superioris is described with the anatomy of the eye.

The **Orbicularis oculi** (figs. 555, 557) is a broad, flat, elliptical muscle which

FIG. 557.—A dissection to expose the right Orbicularis oculi muscle from behind.



Note.—A red probe has been passed from the inferior meatus of the nose into the nasolacrimal duct and has been exposed as it enters the lacrimal sac.

occupies the eyelids, surrounds the circumference of the orbit, spreads over the temporal region, and downwards on the cheek. It consists of three main portions—orbital, palpebral and lacrimal.

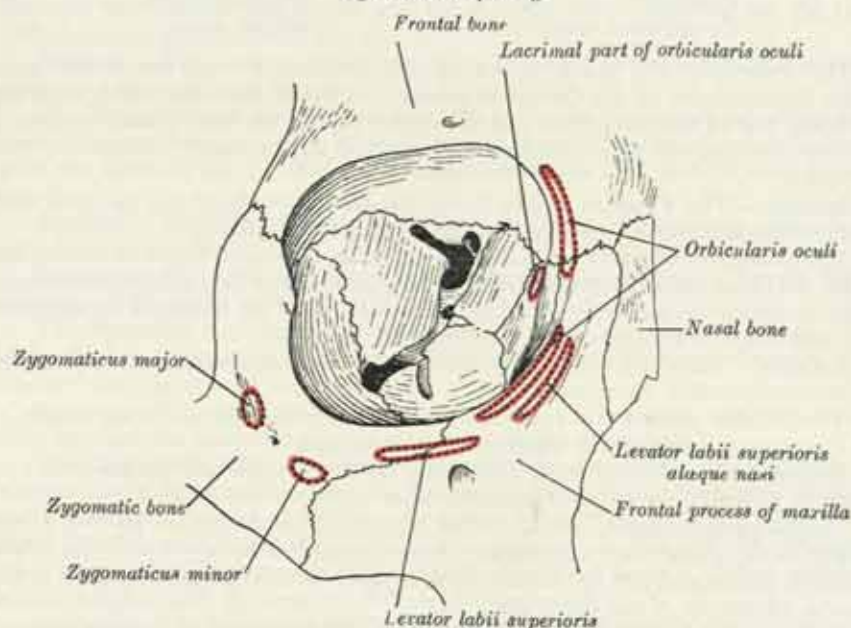
The *orbital portion* of the Orbicularis oculi, of a reddish colour and thicker than the palpebral portion, arises from the nasal part of the frontal bone, from the frontal process of the maxilla (fig. 558), and from the medial palpebral ligament, which interrupts the line of the bony origin. Its fibres form complete ellipses without interruption on the lateral side, the upper fibres blending with the Frontal belly of Occipitofrontalis and the Corrugator. Many fibres from the upper part of the orbital portion are inserted into the skin and subcutaneous tissue of the eyebrow. These fibres constitute the *depressor supercilii* muscle.

The *palpebral portion* of the Orbicularis oculi is thin and pale; it arises from the medial palpebral ligament, chiefly from its superficial and partly from its deep surface, but not from its lower margin; it arises also from the bone immediately above and below the ligament. The muscular fibres sweep across the eyelids in front of the orbital septum (p. 1259) and at the lateral commissure interlace to form the lateral palpebral raphe. A small bundle of very fine fibres lies close to the margin of each eyelid, behind the eyelashes; it is named the *ciliary bundle*.

The *lacrimal portion* of the Orbicularis oculi lies behind the lacrimal sac, but is separated from it by the lacrimal fascia. It arises from the fascia covering the lacrimal sac, from the upper part of the crest of the lacrimal bone, and from the adjacent part of the lateral surface of the lacrimal bone (fig. 558). Passing laterally behind the lacrimal sac the muscle divides into an upper and a lower slip; some of the fibres of these slips are inserted into the tarsi of the eyelids and are closely related to the lacrimal canaliculi, but most of them are continued across the eyelids in front of the tarsi and interlace in the lateral palpebral raphe.

The *medial palpebral ligament*, about 4 mm. in length and 2 mm. in breadth,

FIG. 558.—A sketch showing the attachments of the muscles around the right orbital opening.



is attached to the frontal process of the maxilla in front of the nasolacrimal groove. Crossing the lacrimal sac, it divides into an upper and a lower part, each of which is attached to the medial end of the corresponding tarsus. It is separated from the lacrimal sac by the lacrimal fascia.

The *lateral palpebral raphe* is a much weaker structure than the medial palpebral ligament. It is formed by the interlacing of the lateral ends of the palpebral fibres of the Orbicularis oculi, strengthened on its deep surface by the orbital septum. A few lobules of the lacrimal gland or, more frequently, a small lobule of fat may lie between it and the more deeply placed lateral palpebral ligament (Whitnall), which is described with the anatomy of the eye.

Nerve-supply.—The Orbicularis oculi is supplied by the temporal and zygomatic branches of the facial nerve.

Actions.—The Orbicularis oculi is the sphincter muscle of the eyelids. The palpebral portion acts involuntarily, closing the lids gently, as in sleep or in blinking; the orbital portion is subject to the will. When the entire muscle is brought into action, the skin of the forehead, temple, and cheek is drawn towards the medial angle of the orbit and the eyelids are firmly closed. The skin thus drawn upon is thrown into folds, especially radiating from the lateral angle of the eyelids;

these folds become permanent in old age, and form the so-called 'crow's feet'. The Levator palpebræ superioris is the direct antagonist of this muscle since it raises the upper eyelid and exposes the front of the bulb of the eye. The lacrimal part of the Orbicularis oculi draws the eyelids and the papillæ lacrimales medially; at the same time it exerts traction on the lacrimal fascia and so dilates the lacrimal sac (*see also* p. 1262).

The **Corrugator supercilii** is a small pyramidal muscle, placed at the medial end of the eyebrow, deep to the Frontal belly of Occipitofrontalis and to the Orbicularis oculi. It arises from the medial end of the superciliary arch; and its fibres pass laterally and slightly upwards, and are inserted into the deep surface of the skin, above the middle of the supra-orbital margin.

Nerve-supply.—The Corrugator supercilii is supplied by the temporal branches of the facial nerve.

Actions.—The Corrugator supercilii draws the eyebrow medially and downwards, producing the vertical wrinkles of the forehead. It is the 'frowning' muscle, and may be regarded as the principal muscle in the expression of suffering.

(C) *The Muscles of the Nose* (fig. 555)

Procerus.

Compressor naris.

Depressor septi.

Dilator naris.

The **Procerus** is a small pyramidal slip continuous with the medial part of the Frontal belly of the Occipitofrontalis. It arises from the fascia covering the lower part of the nasal bone and the upper part of the lateral nasal cartilage; it is inserted into the skin over the lower part of the forehead between the two eyebrows.

Actions.—The Procerus draws down the medial angle of the eyebrow and produces the transverse wrinkles over the bridge of the nose.

The **Compressor naris** arises from the maxilla, above and lateral to the incisor teeth; its fibres proceed upwards and medially, and expand into a thin aponeurosis, which is continuous on the bridge of the nose with that of the muscle of the opposite side, and with the aponeurosis of the Procerus.

Actions.—The Compressor naris compresses the nasal aperture at the junction of the vestibule with the nasal cavity.

The **Dilator naris** arises from the maxilla below and medial to the origin of the Compressor naris, and is inserted into the ala nasi.

Actions.—The Dilator naris draws the ala downwards and laterally, and so assists in widening the anterior nasal aperture.

The **Depressor septi**, which is often regarded as a constituent portion of the Dilator naris, arises from the maxilla above the central incisor tooth; its fibres ascend to be inserted into the septum mobile nasi. It lies immediately deep to the mucous membrane of the upper lip.

Actions.—The Depressor septi assists the Dilator naris to widen the nasal aperture.

Nerve-supply.—All the muscles of this group are supplied by the upper buccal branches of the facial nerve.

(D) *The Muscles of the Mouth* (fig. 555)

Levator labii superioris alæque nasi.

Levator labii superioris.

Zygomaticus minor.

Levator anguli oris.

Zygomaticus major.

Mentalis.

Depressor labii inferioris.

Depressor anguli oris.

Buccinator.

Orbicularis oris.

Risorius.

The **Levator labii superioris alæque nasi** arises from the upper part of the frontal process of the maxilla, and passing obliquely downwards and laterally divides into medial and lateral slips. The medial slip is inserted into the greater alar cartilage and skin of the nose; the lateral slip is prolonged into the lateral part of the upper lip, and blends with the Levator labii superioris and with the Orbicularis oris.

Actions.—The lateral slip raises and everts the upper lip; the medial slip acts as a dilator of the nostril.

The **Levator labii superioris** arises from the lower margin of the orbital opening immediately above the infra-orbital foramen, some of its fibres arising from the maxilla and others from the zygomatic bone. Its fibres converge to be inserted into the muscular substance of the upper lip between the lateral slip of the Levator labii superioris alæque nasi and the Levator anguli oris.

Actions.—The Levator labii superioris raises and everts the upper lip. It assists the Zygomaticus minor to form the nasolabial furrow, which passes from the side of the nose to the upper lip, and gives to the face an expression of sadness.

The **Zygomaticus minor** arises from the lateral surface of the zygomatic bone immediately behind the zygomaticomaxillary suture, and passes downwards and medially to be inserted into the muscular substance of the upper lip. It is separated from the Levator labii superioris by a narrow interval (fig. 555).

Actions.—The Zygomaticus minor assists in elevating the upper lip and in the production of the nasolabial furrow. When the Levator labii superioris alæque nasi, the Levator labii superioris and the Zygomaticus minor are in action together, they give to the countenance the expression of contempt and disdain.

The **Levator anguli oris** arises from the canine fossa, just below the infra-orbital foramen, and is inserted into the angle of the mouth, intermingling with the fibres of the Zygomaticus major, Depressor anguli oris, and Orbicularis oris. Between the Levator anguli oris and the Levator labii superioris are the infra-orbital vessels and plexus of nerves.

Actions.—The Levator anguli oris raises the angle of the mouth and assists in producing the nasolabial furrow.

The **Zygomaticus major** arises from the zygomatic bone, in front of the zygomatico-temporal suture, and is inserted into the angle of the mouth, where it blends with the fibres of the Levator anguli oris, Orbicularis oris, and Depressor anguli oris.*

Actions.—The Zygomaticus major draws the angle of the mouth upwards and laterally as in laughing.

Nerve-supply.—All the five preceding muscles are supplied by the buccal branches of the facial nerve.

The **Mentalis** is a conical fasciculus, situated at the side of the frenulum of the lower lip. It arises from the incisive fossa of the mandible and descends to be inserted into the skin of the chin.

Actions.—The Mentalis raises and protrudes the lower lip, and at the same time wrinkles the skin of the chin, expressing doubt or disdain.

The **Depressor labii inferioris** is a quadrilateral muscle. It arises from the oblique line of the mandible, between the symphysis menti and the mental foramen, and passes upwards and medially, to be inserted into the skin of the lower lip, its fibres blending with those of its fellow of the opposite side and with the Orbicularis oris. At its origin it is continuous with the fibres of the Platysma. Much yellow fat is intermingled with the superficial fibres of this muscle.

Actions.—The Depressor labii inferioris draws the lower lip downwards and a little laterally, as in the expression of irony.

The **Depressor anguli oris** arises from the oblique line of the mandible, below and lateral to the Depressor labii inferioris; its fibres converge and are inserted by a narrow fasciculus into the angle of the mouth. At its origin it is continuous with the Platysma, and at its insertion with the Orbicularis oris and Risorius; some of its fibres are directly continuous with those of the Levator anguli oris, and others are occasionally found crossing from the muscle of one side to that of the other; these latter fibres constitute the *Transversus menti*.

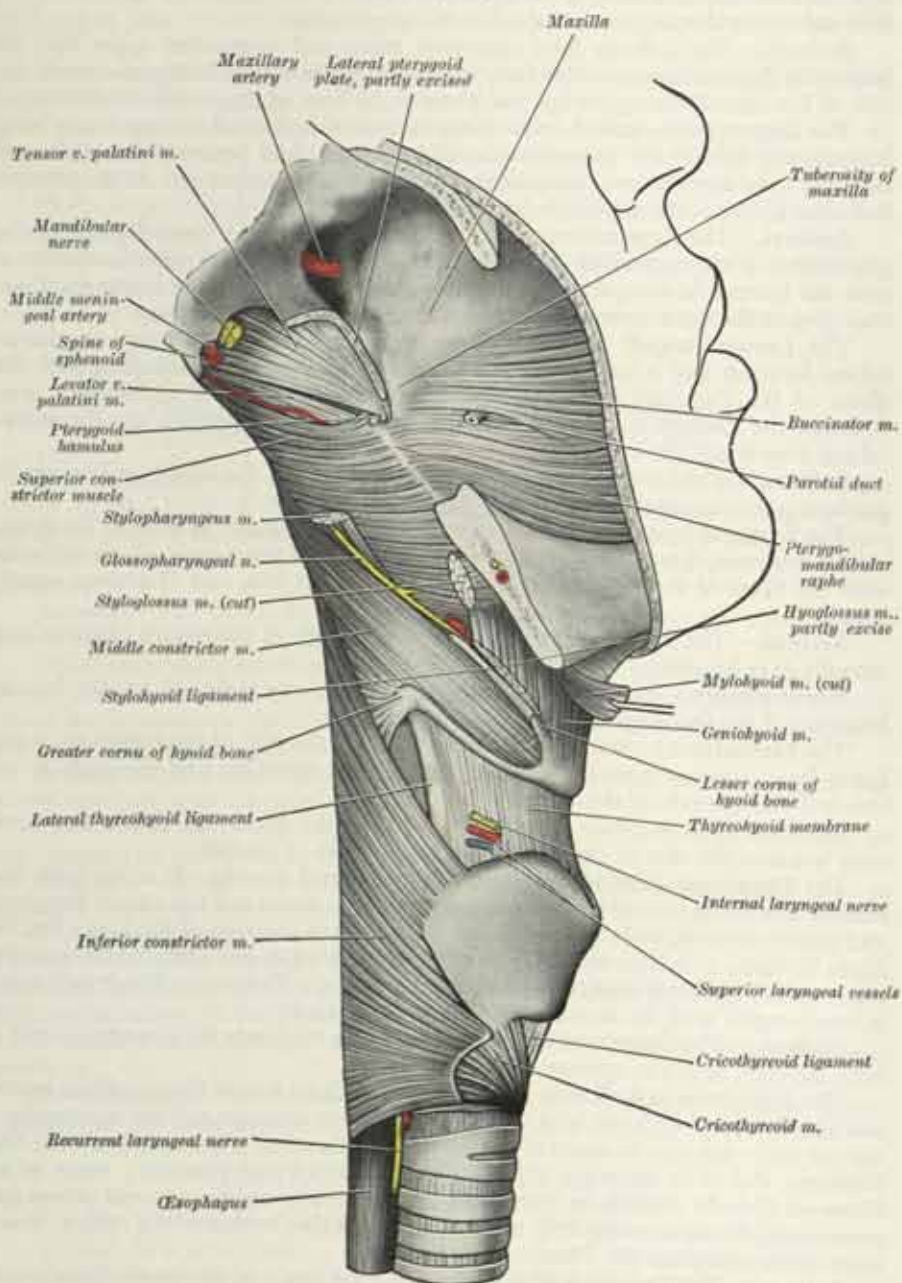
Actions.—The Depressor anguli oris draws the angle of the mouth downwards and laterally.

Nerve-supply.—The Mentalis, the Depressor labii inferioris and the Depressor anguli oris are all supplied by the mandibular marginal branch of the facial nerve.

The **Buccinator** (fig. 559) is a thin quadrilateral muscle, occupying the interval between the maxilla and the mandible, at the side of the face. It arises from the outer surfaces of the alveolar processes of the maxilla and mandible, opposite to the three molar teeth; and, behind, from the anterior border of the pterygomandibular

* The Zygomaticus major and minor and the Levator labii superioris are sometimes more or less concealed by a thin sheet of muscle, named the *Musculus malaris*, and continuous with the Orbicularis oculi. (G. H. S. Lightoller, *J. Anat.*, Lond., 60, 1925.)

FIG. 559.—A dissection to display the Buccinator muscle and the muscles of the pharynx.



Note.—The zygomatic arch and the Masseter muscle, the ramus of the mandible and the Temporalis muscle, and a large portion of the lateral pterygoid plate and the Pterygoid muscles have all been removed. In addition, the upper parts of the Stylopharyngeus and Styloglossus muscles have been excised, together with the postero-inferior part of the Hyoglossus and all the infrahyoid muscles.

raphe, which separates the muscle from the Superior constrictor of the pharynx. Between the tuberosity of the maxilla and the upper end of the pterygomandibular raphe a few fibres arise from a fine tendinous band which bridges the interval between the maxilla and the pterygoid hamulus. The tendon of the Tensor veli palatini on its way to the soft palate pierces the pharyngeal wall in the small gap which lies behind this tendinous band (fig. 559). The fibres of the Buccinator converge towards the angle of the mouth, where the central fibres intersect each other, those from below being continuous with the upper segment of the Orbicularis oris, and those from above with the lower segment; the highest and lowest fibres are continued forward into the corresponding lip without decussation.

Relations.—The Buccinator is on the same plane as the Superior Constrictor of the pharynx and is covered by the buccopharyngeal fascia. It is in relation by its *superficial surface*, behind, with a large mass of fat, which separates it from the ramus of the mandible, the Masseter and a small portion of the Temporalis; this fat was originally named the *suctorial pad*, but its association with the act of sucking is no longer credited. In front the superficial surface of the Buccinator is in relation with Zygomaticus major, Risorius, Levator and Depressor anguli oris, and the parotid duct, which pierces it opposite the second molar tooth of the maxilla; the facial artery and facial vein cross it from below upwards; it is also crossed by branches of the facial and buccal nerves. The *deep surface* is in relation with the buccal glands and mucous membrane of the mouth.

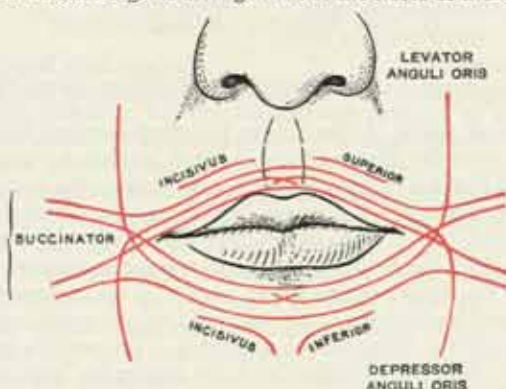
Nerve-supply.—The Buccinator is supplied by the lower buccal branches of the facial nerve.

Actions.—The Buccinator muscles compress the cheeks against the teeth, so that during the process of mastication the food is kept under the immediate pressure of the teeth. When the cheeks have been previously distended with air, the Buccinators expel it between the lips, as in blowing a trumpet; hence the name (*buccina*, a trumpet).

The *pterygomandibular raphe* is a tendinous band which is attached above to the hamulus of the medial pterygoid plate, and below to the posterior end of the mylohyoid line of the mandible. *Medially* it is covered by the mucous membrane of the mouth. *Laterally* it is separated from the ramus of the mandible by a quantity of adipose tissue. *Posteriorly* it gives attachment to the Superior constrictor of the pharynx, and *anteriorly* to a part of the Buccinator (fig. 559).

The **Orbicularis oris** (figs. 555, 560) is not a simple sphincter muscle like the Orbicularis oculi; it is made up of several strata of fibres which surround the orifice

FIG. 560.—A scheme showing the arrangement of the fibres of the Orbicularis oris.



of the mouth but have different directions. It consists partly of fibres derived from the other facial muscles which are inserted into the lips, and partly of fibres proper to the lips. Of the former, a considerable number are derived from the Buccinator, and form the deeper stratum of the Orbicularis. Some of the Buccinator fibres—namely, those near the middle of the muscle—decussate at the angle of the mouth; the uppermost and lowermost fibres pass across the lips from side to side without decussation. Superficial to this is a second stratum, formed by the Levator and Depressor anguli oris, which cross each other at the angle of the mouth; the fibres from the Levator pass to the lower lip, and those from the

Depressor to the upper lip, along which they run, to be inserted into the skin near the anterior median line. Fibres are also derived from the Levator labii superioris, the Zygomaticus major and minor, and the Depressor labii inferioris; these intermingle with the transverse fibres described above, and have principally an oblique direction. Some eight or nine muscles thus converge on each of the two angles of the mouth and interlace here at a palpable nodular mass which is often termed the *modiolus*. This can be fixed in a given position by the combined action of the Zygomaticus major, Levator anguli oris and the Depressor anguli oris muscles. These thus serve to fix the attachments of the Orbicularis oris and Buccinator muscles in this area. Within the lips the fibres of the Orbicularis oris are divisible into two fasciculi, the marginal and peripheral. These combine laterally to form the labial bands which are traceable to the *modiolus*.* The proper fibres of the lips are oblique, and pass from the deep surface of the skin to the mucous membrane, through the thickness of the lip. Finally there are fibres by which the muscle is connected with the maxillæ, above, and with the mandible, below. In the upper lip these constitute the *m. incisivus labii superioris*, which arises from the alveolar border of the maxilla, opposite the lateral incisor tooth, and arching laterally is continuous with the other muscles at the angle of the mouth. The additional fibres for the lower lip constitute a slip (*m. incisivus labii inferioris*) on each side; this slip arises from the mandible, lateral to the Mentalis, and mingles with the other muscles at the angle of the mouth.

Nerve-supply.—The Orbicularis oris is supplied by the lower buccal and the mandibular marginal branches of the facial nerve.

Actions.—The Orbicularis oris in its ordinary action effects the direct closure of the lips; by its deep, assisted by its oblique, fibres, it compresses the lips against the teeth. The superficial part, consisting principally of the decussating fibres, brings the lips together and protrudes them. The orbicularis oris and other muscles of the lip play an important part in articulation.†

The **Risorius** arises from the parotid fascia and is inserted into the skin at the angle of the mouth. It is a narrow bundle of fibres, broadest at its origin, but varying much in its size and form.

Nerve-supply.—The Risorius is supplied by the buccal branches of the facial nerve.

Actions.—The Risorius retracts the angle of the mouth, and produces an unpleasant grinning expression.

II. THE MUSCLES OF MASTICATION

Masseter.
Temporalis.

Pterygoideus lateralis.
Pterygoideus medialis.

A strong layer of fascia, derived from the deep cervical fascia and named the **parotid fascia**, covers the Masseter and is firmly connected with it. It is attached to the lower border of the zygomatic arch, and invests the parotid gland (p. 565).

The **Masseter** (fig. 568) is a quadrilateral muscle, consisting of three superimposed layers which blend with one another anteriorly. The *superficial layer*, the larger, arises by a thick aponeurosis from the zygomatic process of the maxilla, and from the anterior two-thirds of the lower border of the zygomatic arch; its fibres pass downwards and backwards, to be inserted into the angle and lower one-half of the lateral surface of the ramus of the mandible. The *middle layer* arises from the deep surface of the anterior two thirds of the zygomatic arch and from the lower border of the posterior third and is inserted into the middle of the ramus of the mandible. The *deep layer* arises from the deep surface of the zygomatic arch and is inserted into the upper part of the ramus of the mandible and to the coronoid process.‡ On account of its proximity to the skin, the Masseter muscle can be palpated when it is thrown into contraction vigorously, as in clenching the teeth.

* For details of the Orbicularis oris and other muscles of the face see G. H. S. Lightoller, *J. Anat., Lond.*, 60, 1925; 62, 1928. Also A. N. Birkett and G. H. S. Lightoller, *J. Anat., Lond.*, 61 and 62, 1926 and 1927.

† W. L. H. Duckworth, *Some Complexities of Human Structure*, London, 1947.

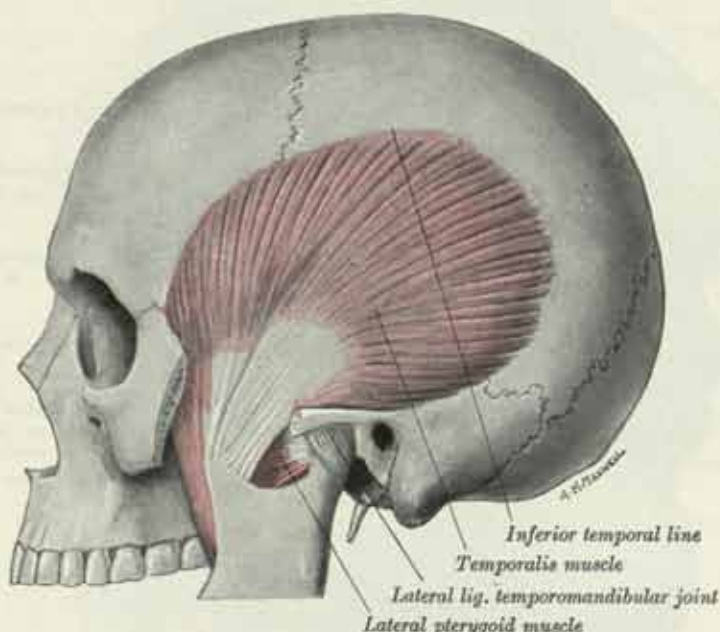
‡ J. D. B. MacDougall, *Brit. dent. J.*, 98, 1955. The middle and deep layers together constitute the deep part of the Masseter of the *Nomina Anatomica*.

Relations.—*Superficial* to the muscle are the integument, the Platysma, the Risorius, the Zygomaticus major, and the parotid gland; the parotid duct, branches of the facial nerve, and the transverse facial vessels cross the muscle. The *deep surface* is in relation with the insertion of the Temporal muscle and the ramus of the mandible; a mass of fat separates it in front from the Buccinator muscle and the buccal nerve. The masseteric nerve and artery reach the deep surface of the muscle by passing through the posterior part of the mandibular notch. The *posterior margin* is overlapped by the parotid gland; the *anterior margin* projects over the Buccinator and is crossed below by the facial vein.

Nerve-supply.—The Masseter is supplied by a branch of the anterior trunk of the mandibular nerve.

Actions.—The Masseter elevates the mandible and presses it against the maxillæ; from its relation to the axis of movement it can act with very great force.

FIG. 561.—The left Temporalis muscle. The zygomatic arch and the Masseter muscle have been removed.



The **temporal fascia** covers the Temporal muscle. It is a strong, fibrous investment, covered, laterally, by the Auriculares anterior et superior, the galea aponeurotica and part of the Orbicularis oculi. The superficial temporal vessels and the auriculotemporal nerve cross it from below upwards. Above, it is a single layer, attached to the entire extent of the superior temporal line; below, it consists of two layers, one of which is attached to the lateral, and the other to the medial margin of the upper border of the zygomatic arch. A small quantity of fat, the zygomatic branch of the superficial temporal artery, and the zygomatico-temporal branch of the maxillary nerve are contained between these two layers. The deep surface of the fascia affords attachment to the superficial fibres of the Temporalis.

The **Temporalis** (fig. 561) is a fan-shaped muscle, situated at the side of the head. It arises from the whole of the temporal fossa (except the portion formed by the zygomatic bone) and from the deep surface of the temporal fascia. Its fibres converge as they descend, and end in a tendon which passes through the gap between the zygomatic arch and the side of the skull, and is inserted into the medial surface, apex, and anterior border of the coronoid process, and the anterior border of the ramus of the mandible nearly down to the last molar tooth.

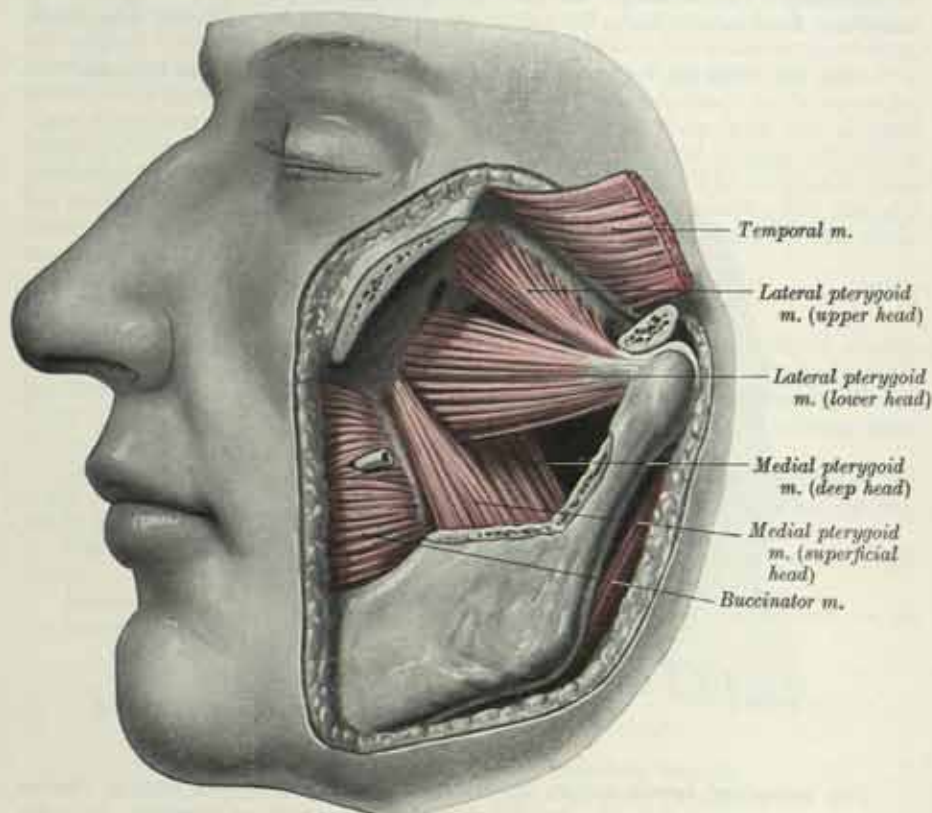
Relations.—*Superficial* to the muscle are the skin, the Auriculares anterior et superior, the temporal fascia, the superficial temporal vessels, the auriculotemporal nerve, the temporal branches of the facial nerve, the zygomaticotemporal nerve, the galea aponeurotica, the zygomatic arch, and the Masseter. The *deep surface* is in relation with the temporal fossa, the Lateral pterygoid, the superficial head of the

Medial pterygoid and a small part of the Buccinator, the maxillary artery and its deep temporal branches, the deep temporal nerves, and the buccal vessels and nerve. Behind the tendon of the muscle the vessels and nerve to the Masseter traverse the mandibular notch. The *anterior border* is separated from the zygomatic bone by a mass of fat.

Nerve-supply.—The Temporalis is supplied by the deep temporal branches of the anterior trunk of the mandibular nerve.

Actions.—The Temporal muscle elevates the mandible and so closes the mouth.

FIG. 562.—The left Pterygoid muscles. The zygomatic arch and a portion of the ramus of the mandible have been removed.



This movement requires both the upward pull of the anterior fibres and the backward pull of the posterior fibres, because the head of the mandible rests on the articular eminence when the mouth is open. The posterior fibres draw the mandible backwards after it has been protruded. Owing to the strength of the temporal fascia, the muscle is not easy to palpate, but its upper limit can be made out along the inferior temporal line when the teeth are firmly clenched.

The **Pterygoideus lateralis** (fig. 562) is a short, thick muscle which arises by two heads: an *upper* from the infratemporal surface and infratemporal crest of the greater wing of the sphenoid bone; and a *lower* from the lateral surface of the lateral pterygoid plate. Its fibres pass backwards and laterally, to be inserted into a depression on the front of the neck of the mandible, and into the articular capsule and disc of the temporomandibular articulation.

Early in the third month of intrauterine life the Lateral pterygoid muscle is inserted into the mesenchyme condensed around the developing condyle of the mandible, but a part of its tendon sweeps backwards above the condyle and gains insertion into that portion of Meckel's cartilage which later forms the head of the malleus.* This part of the tendon becomes converted into the articular disc of the temporomandibular joint, although its attachment to the malleus does not persist.

Relations.—Its *superficial surface* is in relation with the ramus of the mandible,

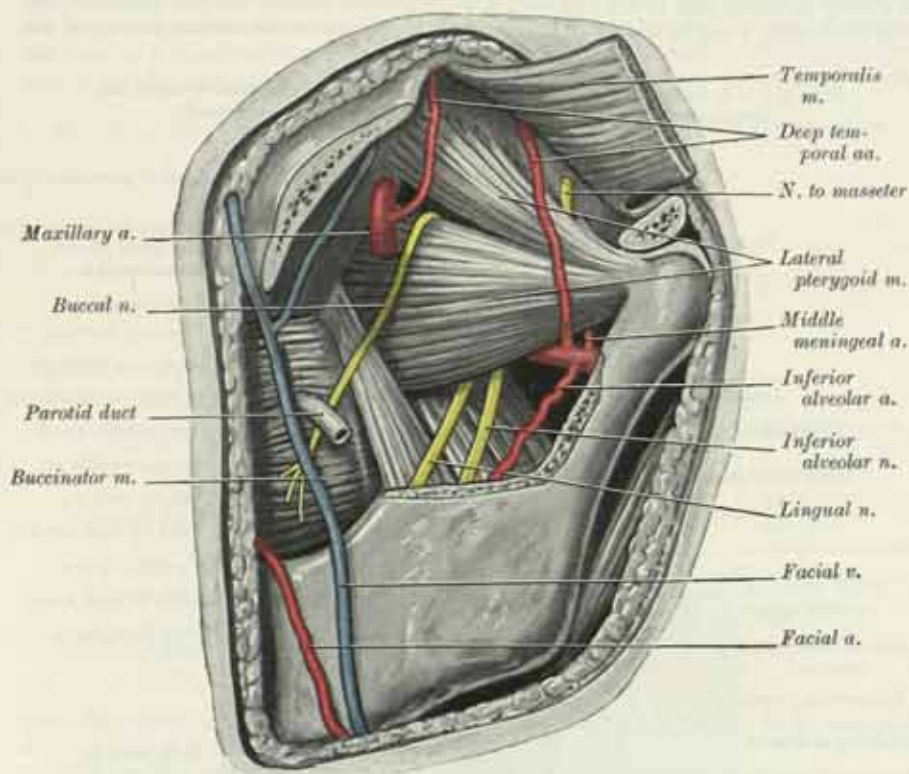
* J. A. Harpman and H. H. Woollard, *J. Anat., Lond.*, 73, 1938.

the maxillary artery, which crosses it,* the tendon of the Temporal muscle and the Masseter. Its *deep surface* rests against the upper part of the Pterygoideus medialis, the sphenomandibular ligament, the middle meningeal artery, and the mandibular nerve; its *upper border* is in relation with the temporal and masseteric branches of the mandibular nerve; its *lower border* with the lingual and inferior alveolar nerves. The buccal nerve and the maxillary artery pass between the heads of the muscle (fig. 563).

Nerve-supply.—The Lateral pterygoid muscle is supplied by a branch from the anterior trunk of the mandibular nerve.

Action.—The Lateral pterygoid muscle assists in opening the mouth by pulling forward the condyloid process of the mandible and the articular disc, while the head

FIG. 563.—The structures in relation with the left Pterygoid muscles.



of the mandible rotates around a bicondylar axis on the articular disc. In the reverse movement of closure of the mouth the backward gliding of the articular disc and condyle of the mandible is controlled by the slow relaxation of the Lateral pterygoid muscle, while the Masseter and Temporalis muscles restore the jaw to the occlusal position. Acting with the Medial pterygoid muscle of the same side the Lateral pterygoid muscle advances the condyle of that side so that the jaw rotates about the opposite condyle. When the Medial and Lateral pterygoid muscles of the two sides act together they protrude the mandible so that the lower incisors are projected in front of the upper.

The **Pterygoideus medialis** (fig. 562), a thick, quadrilateral muscle, arises from the medial surface of the lateral pterygoid plate, and from the grooved surface of the pyramidal process of the palatine bone; it has also a more superficial slip of origin which arises from the lateral surfaces of the pyramidal process of the palatine bone and tuberosity of the maxilla, and lies at first on the surface of the lower part of the lower head of the Lateral pterygoid muscle. Its fibres pass downwards, laterally, and backwards, and are inserted, by a strong tendinous lamina, into the lower and back part of the medial surfaces of the ramus and angle of the mandible, as

* The artery often lies deep to the muscle, as shown in fig. 563.

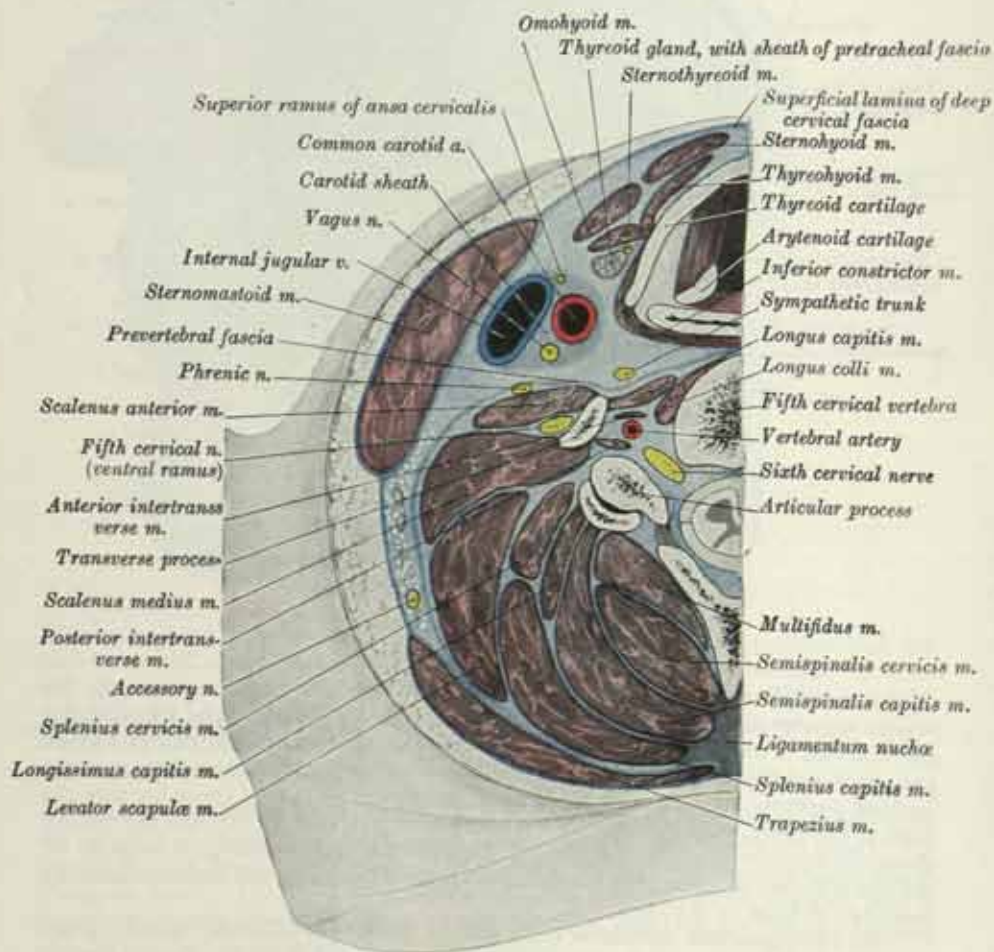
high as the mandibular foramen and nearly as far forwards as the mylohyoid groove (fig. 320).

Relations.—The *lateral surface* of the muscle is in relation with the ramus of the mandible, from which it is separated, at its upper part, by the Lateral pterygoid, the sphenomandibular ligament, the maxillary artery, the inferior alveolar vessels and nerve, the lingual nerve, and a process of the parotid gland. The *medial surface* is in relation with the Tensor veli palatini, and is separated from the Superior constrictor of the pharynx by the Styloglossus, the Stylopharyngeus and some areolar tissue.

Nerve-supply.—The Medial pterygoid muscle is supplied by a branch from the mandibular nerve.

Actions.—The Medial pterygoid muscles assist in elevating the mandible. Acting with the Lateral pterygoids they protrude the mandible. When the two Pterygoid muscles of one side are in action, the corresponding side of the mandible is swung forwards and to the opposite side, while the head of the mandible on that side undergoes a slight degree of rotation (p. 460); by an alternating action of the

FIG. 564.—A transverse section through the left half of the neck to show the arrangement of the deep cervical fascia. Semi-diagrammatic.



muscles of the two sides, the side-to-side movements, which take place during trituration of the food, are effected.

The **Pterygospinous ligament**, which is occasionally replaced by muscle fibres, stretches between the spine of the sphenoid bone and the posterior border of the lateral pterygoid plate near its upper end. It is sometimes ossified and then helps to bound a foramen which transmits the branches of the mandibular nerve destined for the Temporal, Masseter and Lateral pterygoid muscles.

THE FASCIÆ AND MUSCLES OF THE ANTEROLATERAL REGION OF THE NECK

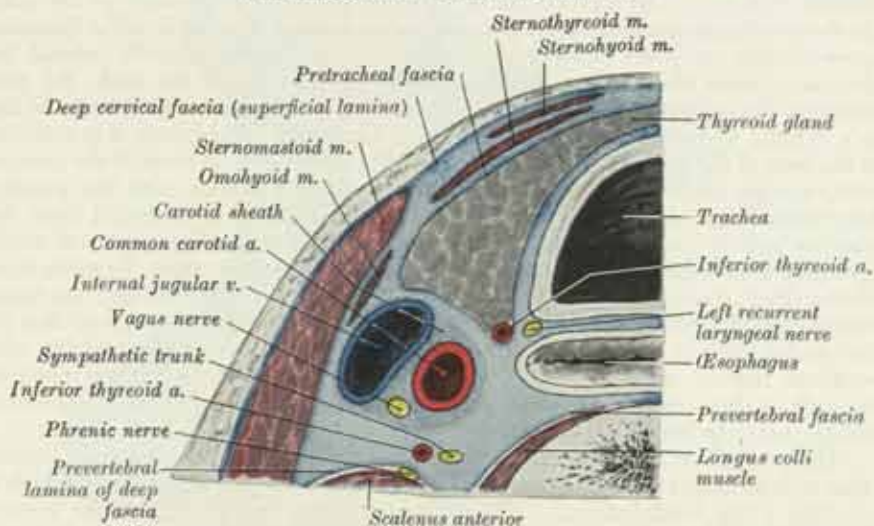
The anterolateral muscles of the neck may be arranged into the following groups:

- | | |
|--------------------------------------|--------------------------|
| I. Superficial and lateral cervical. | III. Anterior vertebral. |
| II. Supra- and infra-hyoid. | IV. Lateral vertebral. |

The **superficial fascia** of the neck is a thin lamina investing the Platysma and is hardly demonstrable as a separate membrane.

The **deep cervical fascia** (fig. 564) lies under cover of the Platysma, and invests the muscles of the neck. It consists of fibro-areolar tissue which occupies all the intervals that would otherwise exist between the muscles, viscera, vessels, etc., of the neck. In certain situations the white fibres predominate, and the fascia assumes the form of a thin fibrous sheet or layer, but elsewhere the tissue is loosely arranged and is easily broken down. It becomes condensed around the blood vessels,

FIG. 565.—Part of a transverse section through the lower part of the neck to show the carotid sheath. Semi-diagrammatic.



providing them with fibrous sheaths which here, as elsewhere in the body, bind the arteries and their accompanying veins closely together.

The **superficial (investing) lamina** of the fascia is attached behind to the ligamentum nuchæ and to the spine of the seventh cervical vertebra. It forms a thin investment for the Trapezius, and from the anterior border of this muscle is continued forwards, as a rather loose areolar layer covering the posterior triangle of the neck, to the posterior border of the Sternocleidomastoid, where it begins to assume the appearance of a fascial membrane. Along the hinder edge of the Sternocleidomastoid it divides to enclose the muscle, and at the anterior margin again forms a single lamina, which covers the anterior triangle of the neck and reaches forwards to the median plane, where it is continuous with the corresponding lamina from the opposite side. In the median plane it is fixed to the symphysis menti and the body of the hyoid bone.

Above, the fascia is attached to the superior nuchal line of the occipital bone, to the mastoid process of the temporal bone, and to the whole length of the base of the mandible. Opposite the angle of the mandible it is very strong, and binds the anterior edge of the Sternocleidomastoid firmly to that bone. Between the mandible and the mastoid process it ensheathes the parotid gland—the layer which covers the gland extends upwards under the name of the **parotid fascia** and is fixed to the zygomatic arch. From the part which passes deep to the parotid gland a strong band ascends to the styloid process, forming the **stylomandibular ligament** (p. 460).

Below, the fascia is attached to the acromion, the clavicle and the manubrium sterni. Some little distance above the last, it splits into a superficial and a deep

layer. The former is attached to the anterior border of the manubrium, the latter to its posterior border and to the interclavicular ligament. Between these two layers there is a slit-like interval, termed the *suprasternal space*; it contains a small quantity of areolar tissue, the lower portions of the anterior jugular veins and the jugular arch, the sternal heads of the Sternomastoid muscles, and sometimes a lymph gland. Over the lower part of the posterior triangle, between the Trapezius and the Sternomastoid muscles, the superficial lamina of deep fascia is also divided into superficial and deep layers. The superficial layer is attached below to the upper border of the clavicle. The deep layer surrounds the inferior belly of the Omohyoid muscle and, deep to the Sternomastoid, the intermediate tendon of the Omohyoid. Below this deep layer blends with the fascia around the Subclavius muscle and is attached to the back of the clavicle and inner end of the first rib.

The *carotid sheath* is a condensation of the cervical fascia in which the common and internal carotid arteries, the internal jugular vein, the vagus nerve and the constituents of the *ansa cervicalis* are imbedded. It is thicker on the arteries than it is on the vein, and peripherally it is connected to the neighbouring layers by loose areolar tissue (fig. 565).

The *prevertebral lamina* of the cervical fascia covers the prevertebral muscles and extends laterally on the Scalenus anterior, the Scalenus medius and the Levator scapulæ muscles, i.e. it forms a fascial floor for the posterior triangle of the neck. As the subclavian artery and the brachial nerves emerge from behind the Scalenus anterior they carry the prevertebral fascia downwards and laterally behind the clavicle to form the *axillary sheath*. Traced laterally round the neck, the prevertebral fascia rapidly becomes thinner and more areolar in character and it is lost as a definite fibrous layer under cover of the Trapezius. Superiorly it is attached to the base of the skull, and inferiorly it is carried downwards in front of the Longus colli muscles into the superior mediastinum, where it blends with the anterior longitudinal ligament. Anteriorly the prevertebral lamina is separated from the pharynx and its covering buccopharyngeal fascia by a loose cellular interval which is termed the *retropharyngeal space*. Further from the median plane, the same loose areolar tissue connects the prevertebral lamina to the carotid sheath and the fascia on the deep surface of the Sternomastoid muscle. It should be observed that all the ventral rami of the cervical nerves lie at first on the deep surface of the prevertebral lamina, and certain of their important branches retain this position throughout their course in the neck, viz. the phrenic, the nerve to the Rhomboids and the nerve to the Serratus anterior muscle.

The *pretracheal lamina* of the cervical fascia is very thin and owes such importance as it possesses to its intimate relationship with the thyroid gland, for which it provides a fine fascial sheath. Above, it is attached to the arch of the cricoid cartilage, and, below, it is continued into the superior mediastinum as an investment for the inferior thyroid veins.

Applied Anatomy.—The deep cervical fascia is of considerable importance from a surgical point of view. The superficial lamina opposes the extension of abscesses towards the surface, and pus forming beneath it has a tendency to extend laterally. If the pus be contained in the anterior triangle, it may find its way into the mediastinum, in front of the pretracheal lamina of fascia; but owing to the thinness of the fascia in this situation it more frequently finds its way to the surface and points above the sternum. Pus forming behind the prevertebral lamina, in cases, for instance, of caries of the bodies of the cervical vertebrae, may extend towards the lateral part of the neck and point in the posterior triangle, or may perforate this layer of fascia and the buccopharyngeal fascia and point into the pharynx (retropharyngeal abscess).

In cases of cut throat, when the wound involves only the superficial lamina the injury is usually trivial, the special danger being injury to the external jugular vein. But where the deeper layers are opened up, important structures may be injured, and serious results follow.

I. THE SUPERFICIAL AND LATERAL CERVICAL MUSCLES

Platysma.

Trapezius.

Sternocleidomastoideus.

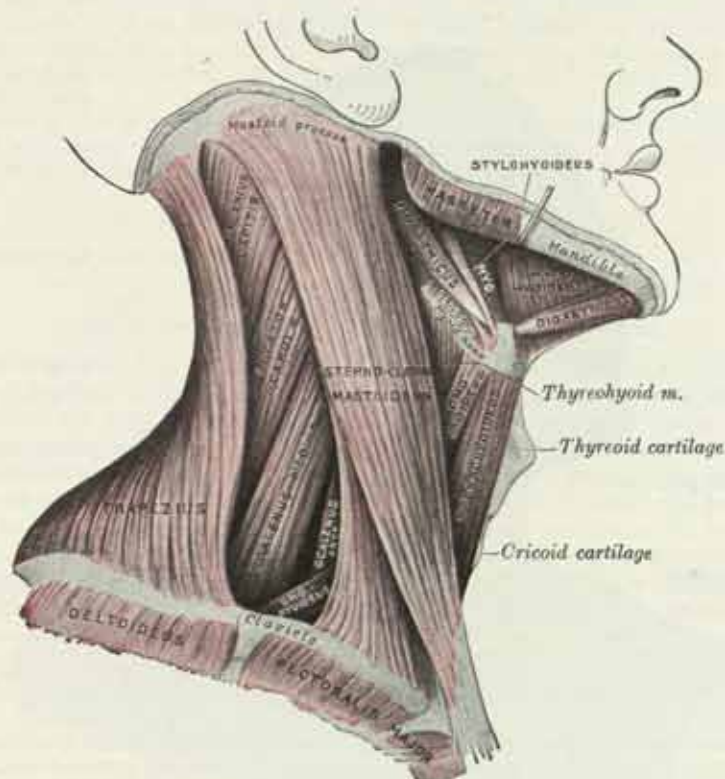
The *Platysma* (fig. 555) is a broad sheet arising from the fascia covering the upper parts of the Pectoralis major and Deltoid; its fibres cross the clavicle, and proceed obliquely upwards and medially in the side of the neck. The anterior

fibres interlace, below and behind the symphysis menti, with the fibres of the muscle of the opposite side; the succeeding fibres are inserted into the lower border of the body of the mandible, while the posterior fibres cross the mandible and the lower, anterior part of the masseter muscle to be inserted into the skin and subcutaneous tissue of the lower part of the face, many of them blending with the muscles about the angle and lower part of the mouth. Under cover of the Platysma, the external jugular vein descends from the angle of the mandible to the middle of the clavicle.

Nerve-supply.—The Platysma is supplied by the cervical branch of the facial nerve.

Actions.—When the entire Platysma is in action it produces a wrinkling of the surface of the skin of the neck in an oblique direction, and tends to diminish the concavity between the jaw and the side of the neck. Its anterior portion, which is

FIG. 566.—The muscles of the neck. Right lateral aspect.



the thickest part of the muscle, may assist in depressing the mandible; it also serves to draw down the lower lip and angle of the mouth in the expression of horror or surprise.

The **Trapezius** is described on p. 611.

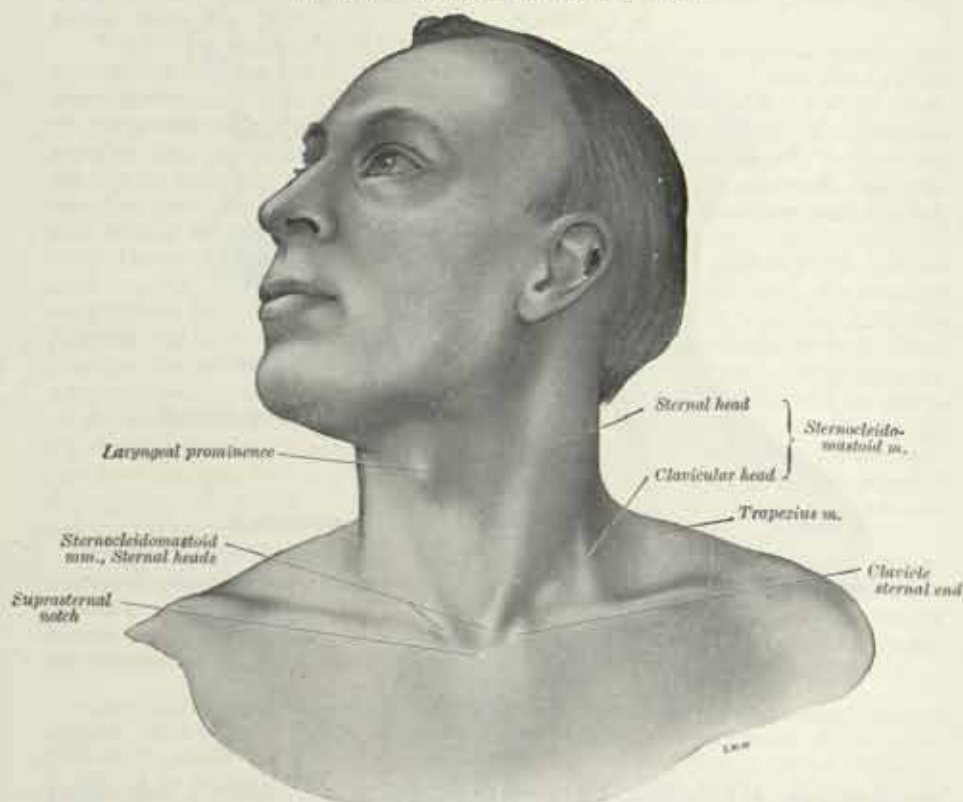
The **Sternocleidomastoid** (fig. 566) passes obliquely across the side of the neck and forms a prominent, visible landmark (fig. 567), especially when it is brought into action. It is thick and narrow at its central part, but broader and thinner at each end. It arises by two heads. The *medial or sternal head* is a rounded tendinous fasciculus, which arises from the upper part of the anterior surface of the manubrium sterni, and is directed upwards, laterally, and backwards. It can be seen and felt in the root of the neck. The *lateral or clavicular head*, composed of fleshy and aponeurotic fibres, arises from the superior border and anterior surface of the medial one-third of the clavicle, and is directed almost vertically upwards. The two heads are separated from each other at their origins by a triangular interval, but, as they ascend, the clavicular head passes under cover of the sternal head and blends with its deep surface below the middle of the neck, forming a thick, rounded belly. The muscle is inserted by a strong tendon into the lateral surface of the mastoid

process, from its apex to its superior border, and by a thin aponeurosis into the lateral half of the superior nuchal line of the occipital bone.

The clavicular head of the Sternocleidomastoid varies in its width; when it is broad it is occasionally subdivided into several slips.

This muscle divides the side of the neck into two triangles, an anterior and a posterior. The boundaries of the *anterior triangle* are, in front, the median line of the neck; above, the base of the mandible, and a line continuing this from the angle of the mandible to the Sternocleidomastoid; behind, the anterior border of the Sternocleidomastoid. The apex of the triangle is at the upper border of the sternum. The boundaries of the *posterior triangle* are, in front, the posterior border of the Sternocleidomastoid; below, the middle one-third of the clavicle; behind, the anterior margin of the Trapezius. The apex corresponds with the meeting of the Sternocleidomastoid and Trapezius on the occipital bone. The subdivisions and contents of these triangles are given on pp. 751 to 754.

FIG. 567.—Surface landmarks of the neck.



Relations.—*Superficial* to the muscle are the skin and Platysma; it is separated from the Platysma by the external jugular vein, the great auricular and transverse cervical nerves, and the superficial lamina of the deep cervical fascia. Near its insertion the muscle is overlapped by a small portion of the parotid gland. The *deep surface* of the muscle is related at its origin to the sternoclavicular joint; it lies upon the Sternohyoid, Sternothyroid and the Omohyoid muscles, while the anterior jugular vein crosses deep to it, but superficial to the infrahyoid muscles, immediately above the clavicle. The carotid sheath and the subclavian artery are deep to these muscles. Between the Omohyoid and the posterior belly of the Digastric the anterior part of the Sternocleidomastoid overlaps the common, internal and external carotid arteries, the internal jugular, facial and lingual veins, the deep cervical lymph glands, the vagus nerve, and the rami of the ansa cervicalis. The sternocleidomastoid branch of the superior thyroid artery crosses deep to the muscle at the upper border of the Omohyoid. The posterior part of the muscle is related deeply to the Splenius, Levator scapulae and Scalenii, the cervical plexus, the upper part of the brachial plexus, the phrenic nerve, and the transverse cervical and suprascapular arteries. The occipital artery crosses deep to the muscle at, or under cover of, the lower border of

the Digastric, where the accessory nerve, which pierces the muscle, runs downwards and laterally deep to it. At its insertion the muscle lies superficial to the mastoid process, and to the Splenius, Longissimus capitis, and the posterior belly of the Digastric.

Nerve-supply.—The Sternocleidomastoid is supplied by the accessory nerve, which traverses it, and by a branch from the ventral ramus of the second (and sometimes of the third) cervical nerve.

Actions.—When one Sternocleidomastoid acts, it tilts the head towards the shoulder of the same side; it also rotates the head so as to carry the face towards the opposite side. Acting together against gravity from their sternoclavicular attachments the two muscles draw the head forwards and so help the Longi colli to flex the cervical part of the vertebral column, e.g. when the head is raised from the pillow while the body is retained in the supine position. If the head be fixed, they assist in elevating the thorax in forced inspiration.

Applied Anatomy.—The deformity known as *wry-neck* is due to a contracted condition of the Sternocleidomastoid. It may be temporary, as the result of direct irritation of the muscle or of the nerves supplying it. It may, however, be permanent, and is then most often due to an injury to the muscle during birth, which results in subsequent ischæmic contracture. In these cases, division of the muscle is often necessary to effect a cure.

There is also a condition coming on in adult life (spasmodic torticollis) which begins with tonic or clonic spasm of one Sternocleidomastoid, soon followed by a spasm of the Trapezius, particularly its clavicular portion.

II. THE SUPRAHYOID AND INFRAHYOID MUSCLES

The suprahyoid muscles are:

Digastricus.
Stylohyoideus.

Mylohyoideus.
Geniohyoideus.

The **Digastric** (fig. 568) consists of two fleshy bellies united by an intermediate rounded tendon. It lies below the body of the mandible, and extends, in a curved form, from the mastoid process to the chin. The *posterior belly*, longer than the anterior, is attached to the mastoid notch of the temporal bone and passes downwards and forwards. The *anterior belly* is attached to the digastric fossa on the base of the mandible close to the median plane, and passes downwards and backwards. The two bellies end in an intermediate tendon, which perforates the Stylohyoid muscle. It is held in connexion with the side of the body and the greater cornu of the hyoid bone by a fibrous loop, which is sometimes lined by a synovial sheath. An aponeurotic layer is given off from the tendon of the Digastric muscle, and is attached to the body and greater cornu of the hyoid bone.

Relations.—Its superficial surface is in relation with the Platysma, Sternomastoid, part of the Splenius, Longissimus capitis, mastoid process, Stylohyoid and the parotid gland. The *deep surface* of the anterior belly lies on the Mylohyoid; that of the posterior belly on the Superior oblique, Rectus capitis lateralis, the transverse process of the atlas vertebra, the accessory nerve, internal jugular vein, occipital artery, hypoglossal nerve, the internal and external carotid, the facial and lingual arteries and the Hyoglossus muscle (fig. 568).

Nerve-supply.—The anterior belly of the Digastric is supplied by the mylohyoid branch of the inferior alveolar nerve; the posterior belly is supplied by the facial nerve.

The **Stylohyoid** (figs. 568, 569) arises by a delicate little tendon from the posterior surface of the styloid process, near its base; and, passing downwards and forwards, is inserted into the body of the hyoid bone, at its junction with the greater cornu, and just above the Omohyoid. It is perforated, near its insertion, by the tendon of the Digastric.

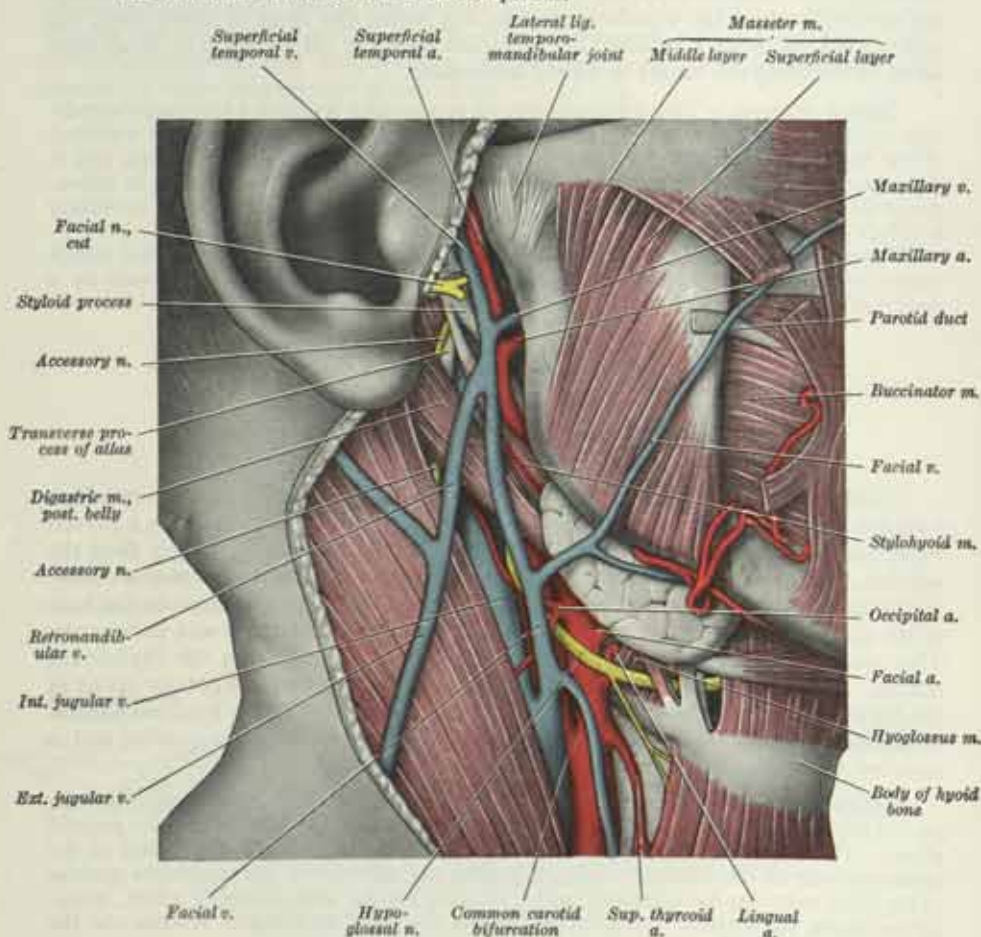
Nerve-supply.—The Stylohyoid is supplied by the facial nerve.

The **stylohyoid ligament**.—In connexion with the Stylohyoid muscle a ligamentous band, named the *stylohyoid ligament*, may be described. It is a fibrous cord, which is attached to the tip of the styloid process of the temporal bone and to the lesser cornu of the hyoid bone. It gives origin to the highest fibres of the Constrictor pharyngis medius and is intimately related to the lateral wall of the oral pharynx (fig. 559). Below, it is covered by the Hyoglossus muscle. It frequently contains a little piece of cartilage in its centre, is often partially ossified, and in

many animals forms a distinct bone, termed the *epihyal*. The stylohyoid ligament represents a portion of the skeletal element of the second visceral arch.

The **Mylohyoid** (figs. 566, 569) is situated deep to the anterior belly of the Digastric, and forms, with its fellow of the opposite side, a muscular floor for the cavity of the mouth. It is a flat, triangular sheet which arises from the whole length of the oblique line of the mandible. The posterior fibres pass medially and slightly downwards, to be inserted into the front of the body of the hyoid bone near

FIG. 568.—Relations of the posterior belly of the Digastric muscle, which has been exposed by the removal of the skin and fasciæ together with the parotid gland and the cutaneous branches of the cervical plexus.



Note.—The facial vein was smaller than usual in this subject.

its lower border. The middle and anterior fibres are inserted into a median fibrous raphe which stretches from the symphysis menti to the hyoid bone. This median raphe is sometimes wanting; if so, the two muscles are continuous.

Relations.—Its *superficial* or *inferior surface* is in relation with the Platysma, the anterior belly of the Digastric, the superficial part of the submandibular gland, the facial and submental vessels, and the mylohyoid vessels and nerve. Its *deep* or *superior surface* is in relation with the Geniohyoid, part of the Hyoglossus, and the Styloglossus muscles, the hypoglossal and lingual nerves, the submandibular ganglion, the sublingual gland, the deep portion of the submandibular gland and the submandibular duct, the lingual and sublingual vessels, and, posteriorly, with the mucous membrane of the mouth.

Nerve-supply.—The Mylohyoid muscle is supplied by the mylohyoid branch of the inferior alveolar nerve.

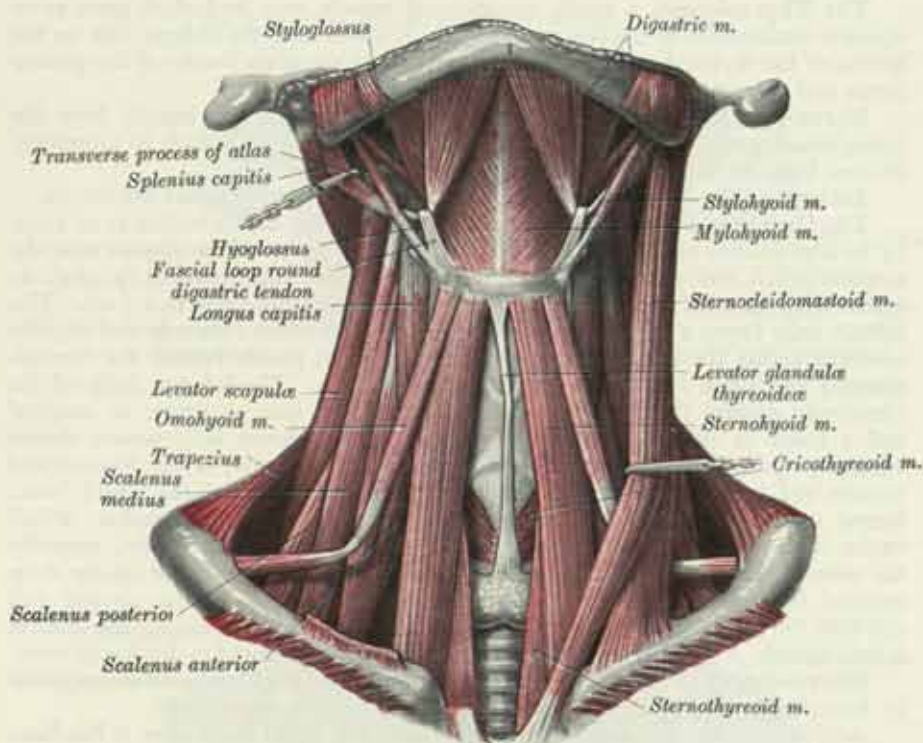
The **Geniohyoid** (fig. 1149) is a narrow muscle, situated above the medial part of the Mylohyoid. It arises from the inferior mental spines on the back of the

symphysis menti, and runs backwards and slightly downwards, to be inserted into the anterior surface of the body of the hyoid bone; it is in contact with its fellow of the opposite side.

Nerve-supply.—The Geniohyoid muscle is supplied by the first cervical nerve through the hypoglossal nerve (p. 1088).

Actions.—The position of the hyoid bone is determined to a large extent by the balanced tonus of the supra- and infra-hyoid groups of muscles, which exercise a steadying effect upon it during the active movements of the tongue in deglutition, mastication and phonation. The suprahyoid muscles elevate the floor of the mouth and the hyoid bone during deglutition and help to fix the bone so as to facilitate the

FIG. 569.—The muscles of the front of the neck.



On the right side the Sternocleidomastoid has been removed.

In this subject, the origin of the Scalenus medius extended up to the transverse process of the atlas.

action of the middle constrictor muscle on the pharynx. The Digastric, Mylohyoid and Geniohyoid muscles are able to open the mouth against resistance.

The infrahyoid muscles are:

Sternohyoideus.

Thyreohyoideus.

Sternothyroideus.

Omohyoideus.

The **Sternohyoid** (figs. 566, 569), a thin, narrow muscle, arises from the posterior surface of the medial end of the clavicle, the posterior sternoclavicular ligament, and the upper and posterior part of the manubrium sterni. Passing upwards and medially, it is inserted into the lower border of the body of the hyoid bone. It sometimes presents, near its origin, a transverse tendinous intersection. Below, the Sternohyoid is separated from its fellow by a considerable interval; but the two muscles usually come into contact with each other in the middle of their course, and are contiguous above.

Nerve-supply.—The Sternohyoid muscle is supplied by branches from the ansa cervicalis.

Action.—The Sternohyoid depresses the hyoid bone after it has been elevated in deglutition. As indicated above, it plays an important part in determining the position of the hyoid bone.

The **Sternothyreoid** (figs. 566, 569) is shorter and wider than the Sternohyoid, and lies under cover of it. It arises from the posterior surface of the manubrium sterni below the origin of the Sternohyoid, and from the edge of the cartilage of the first rib; it is inserted into the oblique line on the lamina of the thyroid cartilage. At the lower part of the neck this muscle is in contact with its fellow, but it diverges as it ascends; it is occasionally traversed by a transverse or oblique tendinous intersection. It is closely applied to the anterolateral surface of the lobe of the thyroid gland.

Nerve-supply.—The Sternothyreoid muscle is supplied by branches from the *ansa cervicalis*.

Action.—The Sternothyreoid draws the larynx downwards after it has been elevated.

The **Thyreohyoid**, a small, quadrilateral muscle, may be looked upon as an upward continuation of the Sternothyreoid. It arises from the oblique line on the lamina of the thyroid cartilage, and is inserted into the lower border of the greater cornu and adjacent part of the body of the hyoid bone.

Nerve-supply.—The Thyreohyoid muscle is supplied by a branch from the hypoglossal nerve. Like the nerve to the Geniohyoid, this branch is ultimately derived from the first cervical nerve.

Actions.—The Thyreohyoid depresses the hyoid bone, or raises the larynx.

The **Omohyoid** (figs. 566, 569) consists of two fleshy bellies united at an angle by an intermediate tendon. It arises from the upper border of the scapula near the scapular notch, and occasionally from the transverse scapular ligament (p. 482), its extent of attachment to the scapula varying from a few millimetres to 2.5 cm. The *inferior belly* forms a flat, narrow fasciculus, which inclines forwards and slightly upwards across the lower part of the neck; it then passes behind the Sternomastoid and there ends in the intermediate tendon. The *inferior belly* of the Omohyoid divides the posterior triangle of the neck into an upper or *occipital* and a lower or *subclavian* triangle (p. 752). The *superior belly* passes almost vertically upwards from this tendon, close to the lateral border of the Sternohyoid muscle, and is inserted into the lower border of the body of the hyoid bone, lateral to the insertion of the Sternohyoid. The intermediate tendon, which varies in length and form, usually lies on the internal jugular vein, opposite the arch of the cricoid cartilage. It is held in position by a band of the deep cervical fascia which ensheathes it and is attached below to the clavicle and the first rib; it is by this fascial process that the angular form of the muscle is maintained. A variable amount of striped muscle may be found in this fascial band.

Nerve-supply.—The superior and inferior bellies of the Omohyoid are supplied by branches from the *ramus superior* and *ansa cervicalis* respectively.

Actions.—The Omohyoid muscle depresses the hyoid bone after it has been elevated. The Omohyoids are concerned also in prolonged inspiratory efforts; by rendering tense the lower part of the deep cervical fascia they lessen the inward suction of the soft parts, which would otherwise compress the great vessels and the apices of the lungs.

III. THE ANTERIOR VERTEBRAL MUSCLES (fig. 570)

Longus colli.

Rectus capitis anterior.

Longus capitis.

Rectus capitis lateralis.

The **Longus colli** is situated on the anterior surface of the vertebral column, between the atlas and the third thoracic vertebra. It is divisible into three portions, an inferior oblique, a superior oblique, and a vertical; its origin and insertion consist of tendinous slips. The *inferior oblique portion*, which is the smallest part of the muscle, arises from the front of the bodies of the first two or three thoracic vertebrae; it runs upwards and laterally, and is inserted into the anterior tubercles of the transverse processes of the fifth and sixth cervical vertebrae. The *superior oblique portion* arises from the anterior tubercles of the transverse processes of the third, fourth and fifth cervical vertebrae; it is directed upwards and medially, and is inserted by a narrow tendon into the anterolateral surface of the tubercle on the anterior arch of the atlas. The *vertical portion* arises from the front of the bodies of the upper three thoracic and lower three cervical vertebrae, and is inserted into the front of the bodies of the second, third and fourth cervical vertebrae.

Nerve-supply.—The Longus colli is supplied by branches from the ventral rami of the second, third, fourth, fifth and sixth cervical nerves.

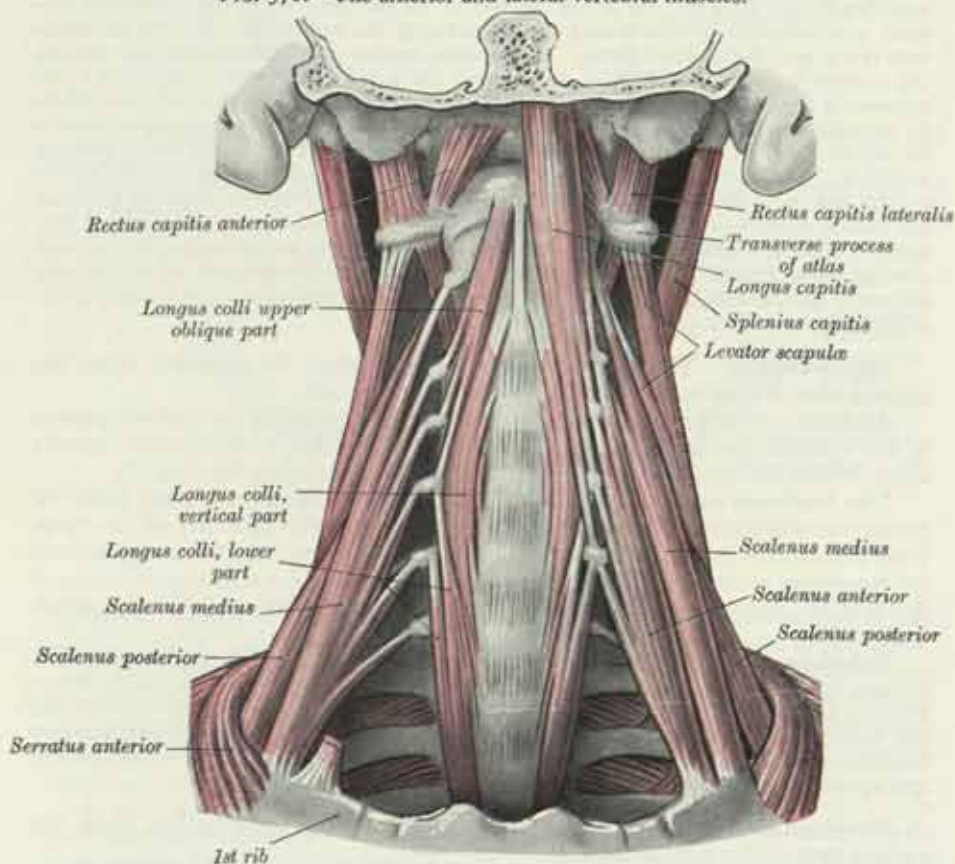
Actions.—The Longus colli bends the cervical portion of the vertebral column forwards; in addition, the oblique portions flex the column laterally and the inferior oblique portion rotates it to the opposite side.

The **Longus capitis**, broad and thick above, narrow below, arises by tendinous slips from the anterior tubercles of the transverse processes of the third, fourth, fifth and sixth cervical vertebrae, and is inserted into the inferior surface of the basilar part of the occipital bone.

Nerve-supply.—The Longus capitis is supplied by branches from the ventral rami of the first, second and third cervical nerves.

Action.—The Longus capitis flexes the head.

FIG. 570.—The anterior and lateral vertebral muscles.



On the right side the Scalenus anterior and the Longus capitis have been removed.

The **Rectus capitis anterior** is a short, flat muscle situated behind the upper part of the Longus capitis. It arises from the anterior surface of the lateral mass of the atlas, and from the root of its transverse process, and is inserted into the inferior surface of the basilar part of the occipital bone in front of the occipital condyle.

Nerve-supply.—The Rectus capitis anterior is supplied by branches from the loop between the ventral rami of the first and second cervical nerves.

Action.—The Rectus capitis anterior flexes the head.

The **Rectus capitis lateralis** is a short, flat muscle which arises from the upper surface of the transverse process of the atlas and is inserted into the under surface of the jugular process of the occipital bone. In view of its attachments and its relation to the ventral ramus of the first cervical nerve, the rectus capitis lateralis is regarded as homologous with the posterior intertransverse muscles.

Nerve-supply.—The Rectus capitis lateralis is supplied by branches from the loop between the ventral rami of the first and second cervical nerves.

Action.—The Rectus capitis lateralis bends the head to the same side.

IV. THE LATERAL VERTEBRAL MUSCLES (fig. 570)

Scalenus anterior.

Scalenus medius.

Scalenus posterior.

The **Scalenus anterior** lies deeply at the side of the neck behind the Sternocleidomastoid muscle. It arises from the anterior tubercles of the transverse processes of the third, fourth, fifth, and sixth cervical vertebræ, and descending, almost vertically, is inserted by a narrow, flat tendon into the scalene tubercle on the inner border of the first rib, and into the ridge on the upper surface of the rib in front of the groove for the subclavian artery.

Relations.—*In front* of it are the clavicle, the Subclavius, Sternocleidomastoid, and Omohyoid muscles, the lateral portion of the carotid sheath, the transverse cervical, suprascapular and ascending cervical arteries, the subclavian vein, the prevertebral fascia and the phrenic nerve. Its *posterior surface* is in relation with the pleura, the nerves forming the brachial plexus and the subclavian artery; the latter two separate it from the Scalenus medius. Below, it is separated from the Longus colli by an angular interval (fig. 570), in which the vertebral artery, with its companion vein on its lateral side, ascends to reach the foramen transversarium of the sixth cervical vertebra. The inferior thyroïd artery crosses the interval from the lateral to the medial side near its apex. The sympathetic trunk and its inferior cervical ganglion are closely related to the postero-medial side of this part of the vertebral artery (fig. 996). On the left side the thoracic duct crosses this interval at the level of the seventh cervical vertebra and usually comes into contact with the medial edge of the muscle. Above, it is separated from the Longus capitis by the ascending cervical branch of the inferior thyroïd artery.

Nerve-supply.—The Scalenus anterior is supplied by branches from the ventral rami of the fourth, fifth, and sixth cervical nerves.

Actions.—Acting from below, the Scalenus anterior bends the cervical portion of the vertebral column forwards and laterally and rotates it towards the opposite side. When the muscle acts from above it assists in elevating the first rib.

The **Scalenus medius**, the largest and longest of the Scaleni, arises from the transverse process of the axis and the front of the posterior tubercles of the transverse processes of the lower five cervical vertebræ, and frequently extends upwards to the transverse process of the atlas (fig. 569); it is inserted into the upper surface of the first rib, between the tubercle of the rib and the groove for the subclavian artery.

Relations.—Its *anterolateral surface* is in relation with the Sternomastoid; it is crossed by the clavicle and the Omohyoid; *anteriorly*, it is separated from the Scalenus anterior by the subclavian artery and the cervical nerves. The Levator scapulæ and the Scalenus posterior are posterolateral to it. The upper two roots of the nerve to Serratus anterior and the nerve to the Rhomboids pierce the substance of the muscle and appear on its lateral surface.

Nerve-supply.—The Scalenus medius is supplied by branches from the ventral rami of the cervical nerves.

Actions.—The Scalenus medius, acting from below, bends the cervical part of the vertebral column to the same side; acting from above it helps to raise the first rib. The Scalene muscles, in particular the Scalenus medius, are important accessory muscles of inspiration. They may be active also during quiet breathing in the erect attitude.*

The **Scalenus posterior**, the smallest and deepest of the Scaleni, arises from the posterior tubercles of the transverse processes of the fourth, fifth, and sixth cervical vertebræ, and is inserted by a thin tendon into the outer surface of the second rib, behind the tubercle for the Serratus anterior. It is occasionally blended with the Scalenus medius.

Nerve-supply.—The Scalenus posterior is supplied by branches from the ventral rami of the lower three cervical nerves.

Actions.—The Scalenus posterior bends the lower end of the cervical part of the vertebral column to the same side, when the second rib is fixed; if its upper attachment be fixed it helps to elevate the second rib.

THE FASCIAE AND MUSCLES OF THE TRUNK

The muscles of the trunk may be arranged in six groups :

- | | |
|------------------------------|------------------------------|
| I. Deep muscles of the back. | IV. Muscles of the abdomen. |
| II. Suboccipital muscles. | V. Muscles of the pelvis. |
| III. Muscles of the thorax. | VI. Muscles of the perineum. |

I. THE DEEP MUSCLES OF THE BACK (fig. 572)

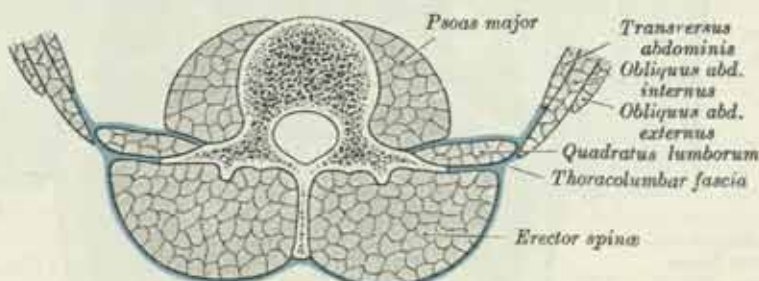
The deep or intrinsic muscles of the back consist of a complex group of muscles extending from the pelvis to the skull. They are :

- | | |
|---------------------|---------------------|
| Splenius capitis. | Splenius cervicis. |
| Erector spinæ. | Transversospinalis. |
| Interspinales. | Semispinalis. |
| Intertransversarii. | Multifidus. |
| | Rotatores. |

The **superficial** and the **deep fascia** of the back of the neck and trunk are described on p. 611.

The **thoracolumbar (lumbar) fascia** covers the deep muscles of the back of

FIG. 571.—A transverse section through the posterior abdominal wall, to show the disposition of the thoracolumbar fascia. Diagrammatic.



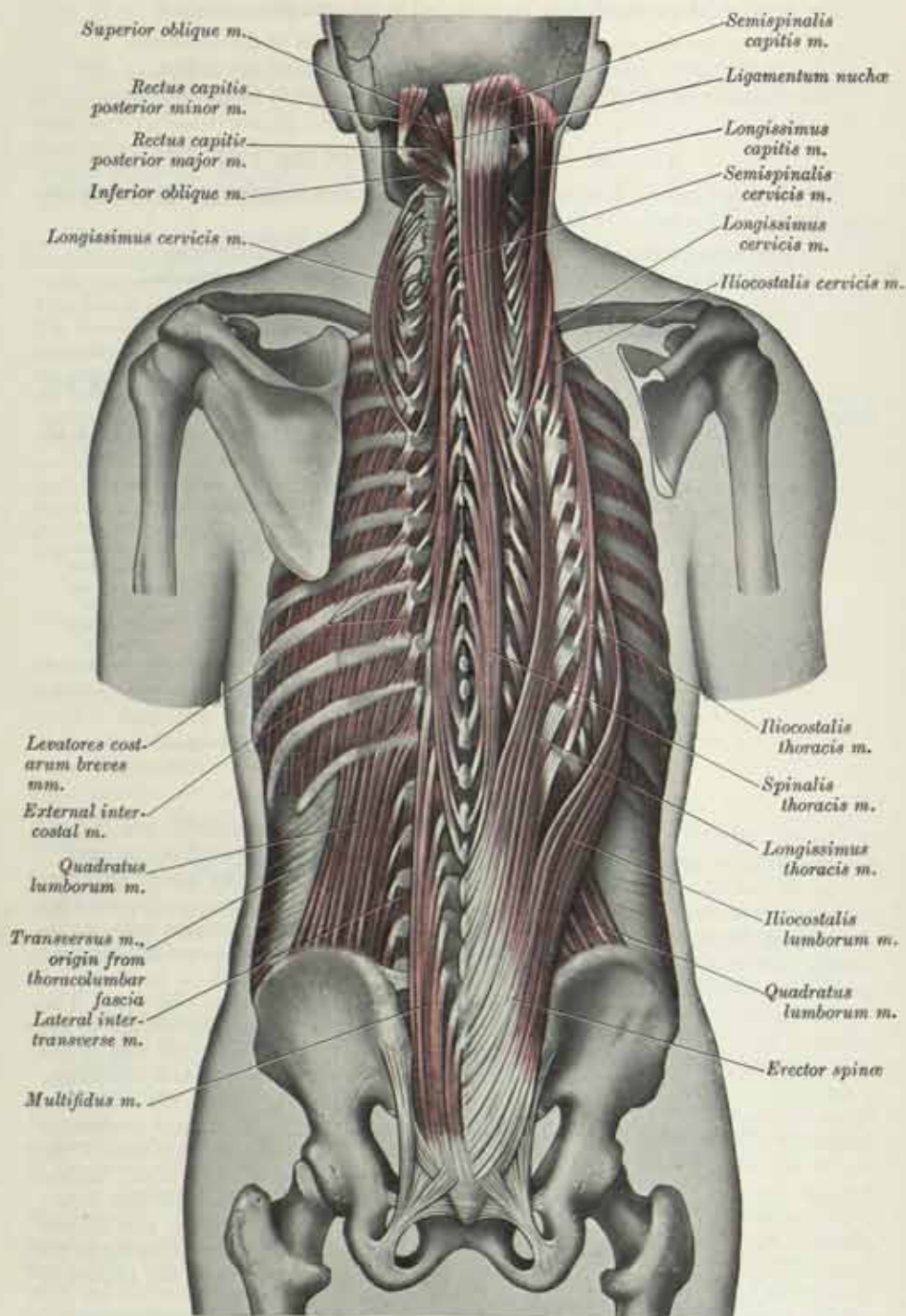
the trunk. Above, it passes in front of the Serratus posterior superior and is continuous with the superficial lamina of the cervical fascia on the back of the neck.

In the thoracic region the thoracolumbar fascia is a thin fibrous lamina covering the extensor muscles of the vertebral column and separating them from the muscles connecting the vertebral column to the upper extremity. It contains both longitudinal and transverse fibres, and is attached, *medially*, to the spines of the thoracic vertebrae; *laterally*, to the angles of the ribs.

In the lumbar region the thoracolumbar fascia is in three layers (fig. 571). The posterior layer is attached to the spines of the lumbar and sacral vertebrae and to the supraspinous ligament; the middle layer is attached, *medially*, to the tips of the transverse processes of the lumbar vertebrae, and to the intertransverse ligaments, *below*, to the iliac crest, and *above*, to the lower border of the twelfth rib and to the lumbocostal ligament (p. 473). The anterior layer covers the Quadratus lumborum and is attached *medially* to the anterior surfaces of the transverse processes of the lumbar vertebrae under cover of the lateral part of the Psoas major muscle. *Below*, it is attached to the iliolumbar ligament and the adjoining part of the iliac crest; *above*, it forms the lateral lumbocostal arch (p. 585). The posterior and middle layers unite at the lateral margin of the Erector spinæ, and at the lateral border of the Quadratus lumborum they are joined by the anterior layer to form the tendon of origin of the Transversus abdominis.

The **Splenius capitis** (fig. 594) arises from the lower half of the ligamentum nuchæ, from the spine of the seventh cervical vertebra, and from the spines of the upper three or four thoracic vertebrae, under cover of the Rhomboid and Trapezius muscles. The fibres of the muscle are directed upwards and laterally and are inserted, under cover of the Sternocleidomastoid muscle, into the mastoid process of the temporal bone, and into the rough surface on the occipital bone just below

FIG. 572.—The deep muscles of the back.



N.B.—On the left side the Erector spinae muscle and its upward continuations (with the exception of the Longissimus cervicis muscle, which has been displaced laterally) together with the Semispinalis capitis muscle have been removed.

the lateral third of the superior nuchal line. The muscle forms a part of the floor of the posterior triangle of the neck, above and behind the Levator scapulæ.

Nerve-supply.—The Splenius capitis is supplied by the lateral branches of the dorsal rami of the middle cervical nerves.

The **Splenius cervicis** arises from the spines of the third to the sixth thoracic vertebræ; it is inserted into the posterior tubercles of the transverse processes of the upper two or three cervical vertebræ immediately under cover of the origin of the Levator scapulæ.

Nerve-supply.—The Splenius cervicis is supplied by lateral branches of the dorsal rami of the lower cervical nerves.

Actions.—The Splenii of the two sides, acting together, draw the head directly backwards; acting separately, they draw the head to one side, and slightly rotate it, turning the face to the same side.

The **Erector spinæ (Sacrospinalis)** (fig. 572), and its prolongations in the thoracic and cervical regions lie in the groove on the side of the vertebral column, covered in the lumbar and thoracic regions by the thoracolumbar fascia, the Serratus posterior inferior below, and the Rhomboid and the Splenius muscles above. It forms a large muscular and tendinous mass, which varies in size and constitution at different parts of the vertebral column. In the sacral region it is narrow and pointed, and at its origin chiefly tendinous in structure. In the lumbar region it forms a thick fleshy mass which can readily be felt in the living subject. Its lateral border is marked by a visible groove (fig. 573), and, traced upwards over the back of the thorax, it crosses the ribs at their angles, inclining medially as it ascends.

The Erector spinæ rises from the anterior surface of a broad and thick tendon, which is attached to the median sacral crest, to the spines of the lumbar and the eleventh and twelfth thoracic vertebræ, to the supraspinous ligament, to the medial aspect of the dorsal segment (p. 397) of the iliac crest and to the lateral sacral crest (fig. 263), where it blends with the sacrotuberous and dorsal sacro-iliac ligaments; some of its fibres are continuous with the fibres of origin of the Gluteus maximus. The muscular fibres form a large fleshy mass, which splits in the upper lumbar region into three columns, viz. a lateral, the *Iliocostocervicalis*, an intermediate, the *Longissimus*, and a medial, the *Spinalis*. Each of these consists, from below upwards, of three parts, as follows:

<i>Lateral Column.</i>	<i>Intermediate Column.</i>	<i>Medial Column.</i>
<i>Iliocostocervicalis.</i>	<i>Longissimus.</i>	<i>Spinalis.</i>
(a) <i>Iliocostalis lumborum.</i>	(a) <i>L. thoracis.</i>	(a) <i>S. thoracis.</i>
(b) <i>Iliocostalis thoracis.</i>	(b) <i>L. cervicis.</i>	(b) <i>S. cervicis.</i>
(c) <i>Iliocostalis cervicis.</i>	(c) <i>L. capitis.</i>	(c) <i>S. capitis.</i>

The **Iliocostalis lumborum** is inserted, by flattened tendons, into the inferior borders of the angles of the lower six or seven ribs.

The **Iliocostalis thoracis** arises from the upper borders of the angles of the lower six ribs medial to the tendons of insertion of the *Iliocostalis lumborum*; it is inserted into the upper borders of the angles of the upper six ribs and into the back of the transverse process of the seventh cervical vertebra.

The **Iliocostalis cervicis** arises from the angles of the third, fourth, fifth and sixth ribs medial to the tendons of insertion of the *Iliocostalis thoracis*, and is inserted into the posterior tubercles of the transverse processes of the fourth, fifth and sixth cervical vertebræ.

Nerve-supply.—These three muscles are supplied by the dorsal rami of the lower cervical, the thoracic and the upper lumbar nerves.

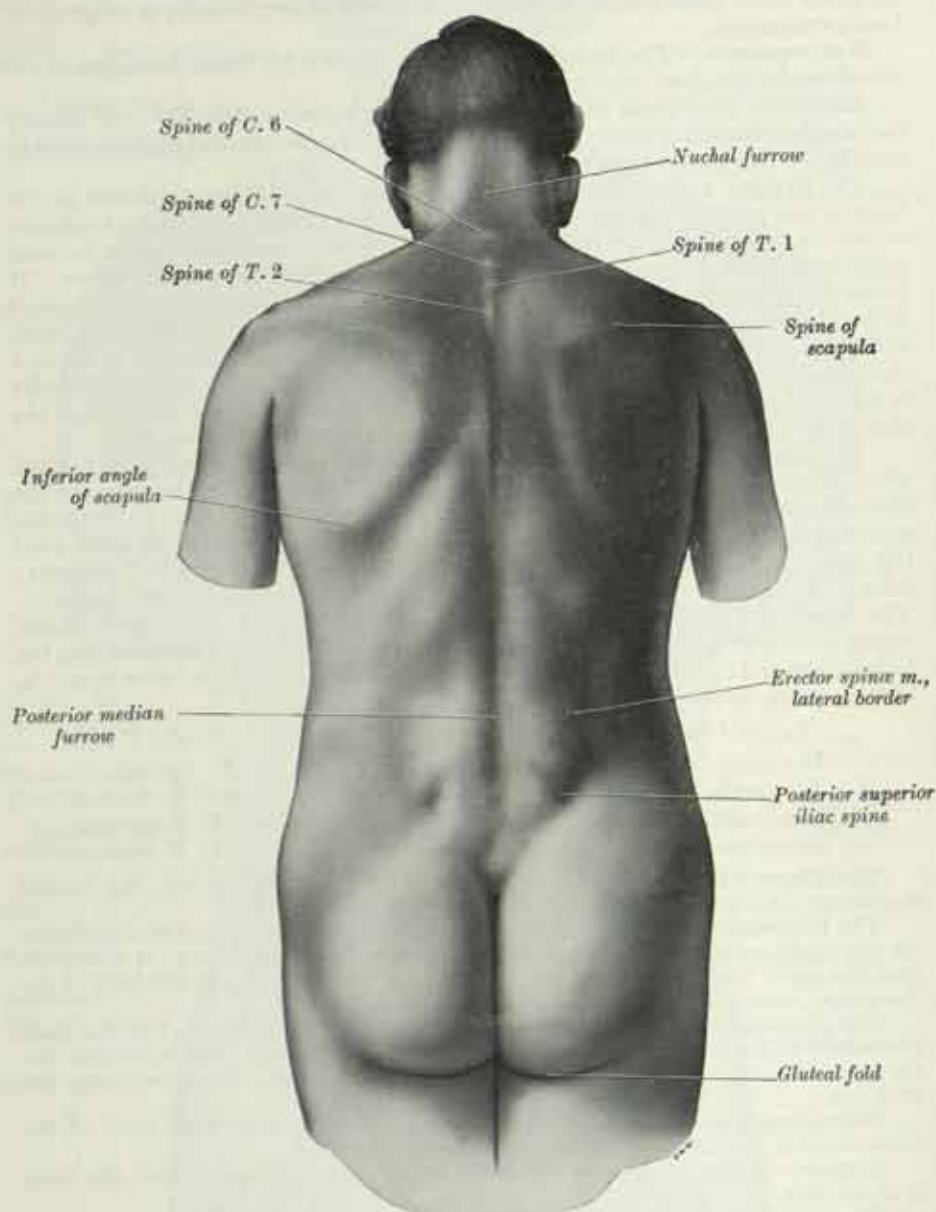
Actions.—These muscles are extensors of the vertebral column; they also bend it to one side.

The **Longissimus thoracis** is the intermediate and largest of the continuations of the Erector spinæ. In the lumbar region, where it is as yet blended with the *Iliocostalis lumborum*, some of its fibres are attached to the whole length of the posterior surfaces of the transverse processes and the accessory processes of the lumbar vertebræ, and to the middle layer of the thoracolumbar fascia. In the thoracic region it is inserted, by rounded tendons, into the tips of the transverse processes of all the thoracic vertebræ, and by fleshy processes into the lower nine or ten ribs between their tubercles and angles.

The **Longissimus cervicis**, situated medial to the *Longissimus thoracis*, arises by long thin tendons from the transverse processes of the upper four or five thoracic vertebræ, and is inserted by similar tendons into the posterior tubercles of the transverse processes of the cervical vertebræ from the second to the sixth inclusive.

The **Longissimus capitis** lies between the Longissimus cervicis and the Semispinalis capitis. It arises by tendons from the transverse processes of the upper four or five thoracic vertebræ, and the articular processes of the lower three or four cervical vertebræ, and is inserted into the posterior margin of the mastoid process, deep to the

FIG. 573.—The dorsal aspect of the trunk, showing the principal surface landmarks.



Splenius capitis and Sternomastoid. It is usually crossed by a tendinous intersection near its insertion.

Nerve-supply.—The Longissimi are supplied by the dorsal rami of the lower cervical, the thoracic and the lumbar nerves.

Actions.—The Longissimi thoracis et cervicis bend the vertebral column backwards and laterally; the Longissimus capitis extends the head, and turns the face towards the same side.

The **Spinalis thoracis**, the medial continuation of the Erector spinæ, is scarcely separable as a distinct muscle. It is situated at the medial side of the Longissimus thoracis, and is intimately blended with it; it arises by three or four tendons from the spines of the eleventh and twelfth thoracic, and first and second lumbar vertebræ;

these, uniting, form a small muscle which is inserted by separate tendons into the spines of the upper thoracic vertebræ, the number varying from four to eight. It is intimately united with the *Semispinalis thoracis*, which lies deep to it.

The *Spinalis cervicis* is an inconstant muscle, which arises from the lower part of the ligamentum nuchæ, the spine of the seventh cervical, and sometimes from the spines of the first and second thoracic vertebræ; it is inserted into the spine of the axis, and occasionally into the spines of the two vertebræ immediately below it.

The *Spinalis capitis* is usually more or less blended with the *Semispinalis capitis*.

Nerve-supply.—The *Spinales* are supplied by the dorsal rami of the lower cervical and thoracic nerves.

Actions.—The *Spinales* extend the vertebral column.

The *Transverso-spinalis* consists of the following muscles :

<i>Semispinalis thoracis.</i>	<i>Multifidus.</i>	<i>Rotatores cervicis.</i>
<i>Semispinalis cervicis.</i>		<i>Rotatores thoracis.</i>
<i>Semispinalis capitis.</i>		<i>Rotatores lumborum.</i>

These muscles run obliquely upwards and medially from the transverse processes to the spines of the vertebræ.

The *Semispinalis thoracis* consists of thin, fleshy fasciculi, interposed between tendons of considerable length. It arises by a series of tendons from the transverse processes of the thoracic vertebræ from the sixth to the tenth inclusive, and is inserted, by tendons, into the spines of the upper four thoracic and lower two cervical vertebræ.

The *Semispinalis cervicis*, thicker than the preceding, arises by a series of tendinous and fleshy fibres from the transverse processes of the upper five or six thoracic vertebræ, and is inserted into the cervical spines, from the axis to the fifth inclusive.

The fasciculus connected with the axis is the largest, and is chiefly muscular in structure. The *Semispinalis capitis* (fig. 572) is situated at the back of the neck, under cover of the *Splenius*, and medial to the *Longissimi cervicis et capitis*. It arises by a series of tendons from the tips of the transverse processes of the upper six or seven thoracic and the seventh cervical vertebræ, from the articular processes of the fourth, fifth, and sixth cervical vertebræ and, occasionally, from the spine of the seventh cervical or first thoracic vertebra. The tendons are succeeded by a broad muscle, which passes upwards and is inserted into the medial part of the area between the superior and inferior nuchal lines of the occipital bone. The medial part, usually more or less distinct from the rest of the muscle, is named the *Spinalis capitis*; it is sometimes called the *Biventer cervicis*, since it is traversed by an imperfect tendinous intersection.

Nerve-supply.—The *Semispinales* are supplied by the dorsal rami of the cervical and thoracic nerves.

Actions.—The *Semispinales thoracis et cervicis* extend the thoracic and cervical portions of the vertebral column, and rotate them towards the opposite side; the *Semispinalis capitis* extends the head, and turns the face slightly towards the opposite side.

The *Multifidus* consists of a number of fleshy and tendinous fasciculi, which lie deep to the foregoing muscles and fill the groove at the side of the spines of the vertebræ, from the sacrum to the axis. In the sacral region, the fasciculi arise from the back of the sacrum as low as the fourth sacral foramen, from the aponeurosis of origin of the *Erector spine*, from the medial surface of the posterior superior iliac spine and from the dorsal sacro-iliac ligaments; in the lumbar region, from all the mamillary processes; in the thoracic region, from all the transverse processes; and in the cervical region, from the articular processes of the lower four vertebræ. Each fasciculus passes obliquely upwards and medially, and is inserted into the whole length of the spine of one of the vertebræ above. The fasciculi vary in length; the most superficial pass from one vertebra to the third or fourth above; those next in depth run from one vertebra to the second or third above; while the deepest connect contiguous vertebræ.

Nerve-supply.—The *Multifidus* is supplied by the dorsal rami of the spinal nerves.

The *Rotatores* lie deep to the *Multifidus* and are best developed in the thoracic region.

The *Rotatores thoracis* are eleven in number on each side, and are small and somewhat quadrilateral in form. Each arises from the upper and posterior part of the transverse process of one vertebra, and is inserted into the lower border and lateral surface of the lamina of the vertebra next above, the fibres extending as far as the root of the spine. The first is found between the first and second thoracic vertebræ; the last, between the eleventh and twelfth. Sometimes the number of these muscles is diminished by the absence of one or more from the upper or lower end of the series.

The *Rotatores cervicis* and *lumborum* are represented only by irregular and variable muscle bundles with similar attachments to those of the *Rotatores thoracis*.

Nerve-supply.—The *Rotatores* are supplied by the dorsal rami of the spinal nerves.

The **Interspinales** are short muscular fasciculi, placed in pairs between the spines of contiguous vertebræ, one on each side of the interspinous ligament. In the *cervical region* they are most distinct, and consist of six pairs; the first is situated between the axis and third vertebra, and the last between the seventh cervical and the first thoracic vertebra. They are small narrow bundles, attached, above and below, to the apices of the spines. In the *thoracic region* they are found between the first and second vertebra, and sometimes between the second and third, and the eleventh and twelfth vertebra. In the *lumbar region* there are four pairs in the intervals between the five lumbar vertebræ. A pair is occasionally found between the last thoracic and first lumbar vertebra, and another between the fifth lumbar vertebra and the sacrum.

Nerve-supply.—The Interspinales are supplied by the dorsal rami of the spinal nerves.

The **Intertransversarii** are small muscles placed between the transverse processes of the vertebræ. They are best developed in the *cervical region* where they consist of anterior and posterior slips, which are separated by the ventral rami of the spinal nerves. The *posterior intertransverse muscles* are subdivisible into medial and lateral slips, which are supplied by the dorsal and ventral rami of the spinal nerves respectively. The medial which is the proper intertransverse muscle is often further subdivided into medial and lateral portions by the passage through it of the dorsal ramus of the spinal nerve. The *anterior intertransverse muscles* and the lateral parts of the posterior muscles connect the costal processes of contiguous vertebræ, and the medial parts of the posterior muscles connect the true transverse processes. There are seven pairs of these muscles, the highest between the atlas and axis, and the lowest between the seventh cervical vertebra and the first thoracic, but the anterior muscle between the atlas and axis is often absent. In the *thoracic region* they consist of single muscles, which are present between the transverse processes of the three lower thoracic vertebræ only and between the transverse processes of the last thoracic vertebra and the first lumbar. In the *lumbar region* they again consist of two sets of muscles, one named the *Intertransversarii mediales*, connecting the accessory process of one vertebra with the mamillary process of the next, and the other named the *Intertransversarii laterales*, which are really divisible into ventral and dorsal parts.* The ventral parts connect the transverse processes (costal elements) of the lumbar vertebræ, and each dorsal part connects the accessory process to the transverse process of the succeeding vertebra.

Nerve-supply.—The *Intertransversarii mediales lumborum*, the thoracic *Intertransversarii* and the medial parts of the posterior *Intertransverse muscles* in the cervical region are supplied by the dorsal rami of the spinal nerves; the others are supplied by the ventral rami.

Actions.—The short muscles of the back function, for the most part, as postural muscles. The vertebral column consists, in effect, of a series of short levers jointed together. A mechanical arrangement of this nature is unstable to compression forces and it will tend to buckle unless there is some mechanism by which the movements of the individual joints relative to one another can be controlled. This mechanism is provided by the short muscles of the back which steady adjoining vertebræ and control their movements during movements of the vertebral column as a whole. In this way they ensure the efficient action of the long muscles.

Theoretically, these muscles are capable of producing extension (*Multifidus*, *Spinales*), lateral flexion (*Multifidus*, *Intertransversarii*), and rotation (*Multifidus* and *Rotatores*), but their functions as prime movers are of quite secondary importance.

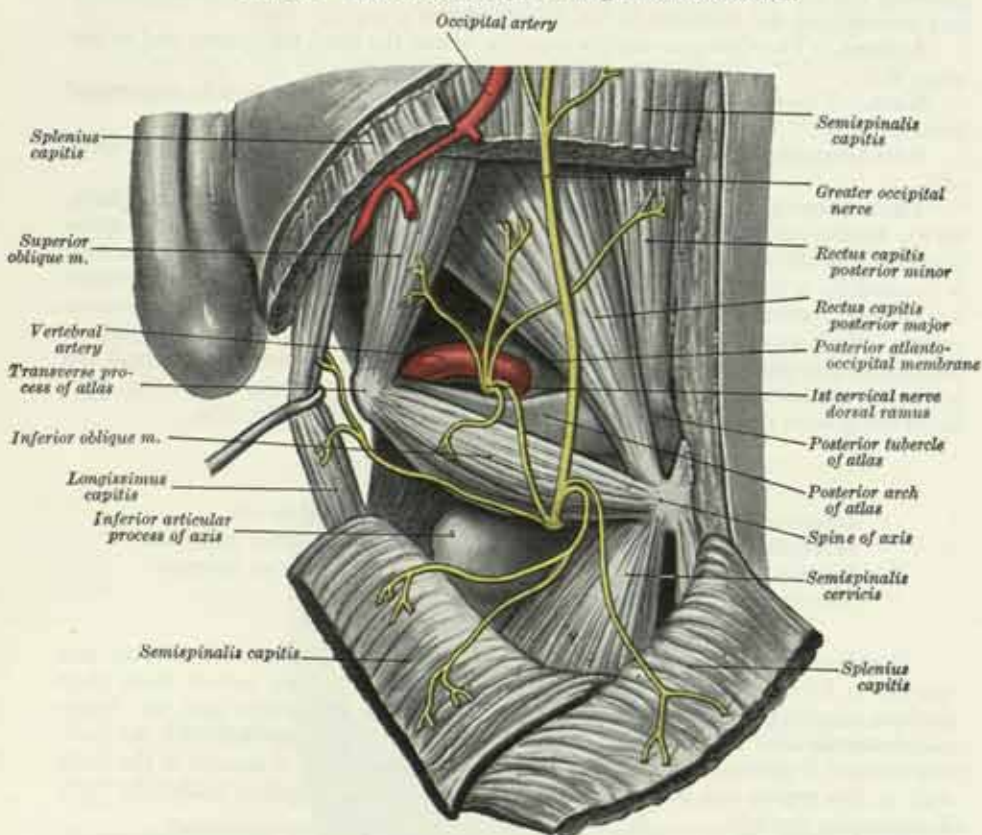
The deep muscles of the back are important in the control of posture. These muscles show intermittent contractions during the spontaneous swaying movements which occur in the upright posture. Contraction of the erector spinæ muscle extends the trunk but the continued control of extension is to a large extent dependent on the activity of the *Rectus abdominis* muscles. Similarly during flexion of the trunk, movement is initiated by the flexor muscles such as the *Rectus abdominis* muscles, but its further control is exercised by the *Erector spinæ* muscles. In lateral flexion the control is exercised by the contralateral *Erector spinæ* muscle. In

* A. J. E. Cave, *J. Anat., Lond.*, 71, 1937. According to A. B. Morrison, *J. Anat., Lond.*, 88, 1954, the Thoracic intertransverse muscles and ligaments are homologous with the medial portions of the proper Posterior intertransverse muscles of the cervical region and the *Levatores costarum* muscles are homologous with the lateral portions. The lateral branch of the dorsal ramus of the spinal nerve separates the Thoracic intertransverse muscle from the *Levator costæ* muscle. In the lumbar region the *Levatores costarum* muscles are represented by the Medial intertransverse muscles while the Lateral intertransverse muscles are homologous with the Intercostal muscles.

the position of full flexion of the trunk the Erector spinæ muscle however is relaxed and electromyographically quiet. It is believed that in this position the tension is totally taken up by the ligament of the spine.*

Applied Anatomy.—If the short muscles of the back are paralysed, contraction of the long muscles, or even their normal myotonus, together with the compressing effect of gravity, will cause the vertebral column to buckle and this produces the deformity known as *scoliosis*.

FIG. 574.—The left suboccipital triangle and its contents.



II. THE SUBOCCIPITAL MUSCLES (fig. 574)

Rectus capitis posterior major.
Rectus capitis posterior minor.

Obliquus capitis inferior.
Obliquus capitis superior.

The **Rectus capitis posterior major** arises by a pointed tendon from the spine of the axis, and, becoming broader as it ascends, is inserted into the lateral part of the inferior nuchal line of the occipital bone, and into the bone immediately below the line. As the muscles of the two sides pass upwards and laterally, they leave between them a triangular space, in which parts of the Recti capitis posteriores minores are seen.

Actions.—The Rectus capitis posterior major extends the head, and turns the face towards the same side.

The **Rectus capitis posterior minor** arises by a narrow pointed tendon from the tubercle on the posterior arch of the atlas, and, widening as it ascends, is inserted into the medial part of the inferior nuchal line of the occipital bone and also into the bone between that line and the foramen magnum (fig. 327).

Action.—The Rectus capitis posterior minor extends the head.

The **Obliquus capitis inferior**, the larger of the two Oblique muscles, arises from the lateral surface of the spine and adjacent part of the upper part of the lamina

* W. F. Floyd and P. H. S. Silver, *J. Physiol.*, 129, 1955.

of the axis; it passes laterally and slightly upwards, to be inserted into the lower and back part of the transverse process of the atlas.

Action.—The *Obliquus capitis inferior* turns the face towards the same side. *Owing to the length of the transverse process of the atlas the muscle is enabled to act to good mechanical advantage.*

The ***Obliquus capitis superior***, narrow below, wide and expanded above, arises by tendinous fibres from the upper surface of the transverse process of the atlas. It passes upwards and backwards, and is inserted into the occipital bone, between the superior and inferior nuchal lines, lateral to the *Semispinalis capitis* and overlapping the insertion of the *Rectus capitis posterior major*.

Actions.—The *Obliquus capitis superior* bends the head backwards and to the same side.

Note.—This muscle and the two *Recti* are employed more frequently as postural muscles (p. 546) than as prime movers.

Nerve-supply.—All the suboccipital muscles are supplied by the dorsal ramus of C. 1.

The **suboccipital triangle**.—This triangle is bounded, above and medially, by the *Rectus capitis posterior major*; above and laterally, by the *Obliquus capitis superior*; below and laterally, by the *Obliquus capitis inferior*. Medially, the roof is formed by a layer of dense fibrofatty tissue, situated deep to the *Semispinalis capitis*, and, laterally, by the *Longissimus capitis* and sometimes by the *Splenius capitis*, which cover the *Obliquus capitis superior*. The floor of the triangle is formed by the posterior atlanto-occipital membrane and the posterior arch of the atlas; the vertebral artery and the dorsal ramus of the first cervical nerve (fig. 574) lie in the groove on the upper surface of the posterior arch of the atlas.

III. THE MUSCLES OF THE THORAX

Intercostales externi.

Intercostales interni.

Intercostales intimi.

Subcostales.

Levatores costarum.

Serratus posterior superior.

Serratus posterior inferior.

Diaphragm.

Transversus thoracis.

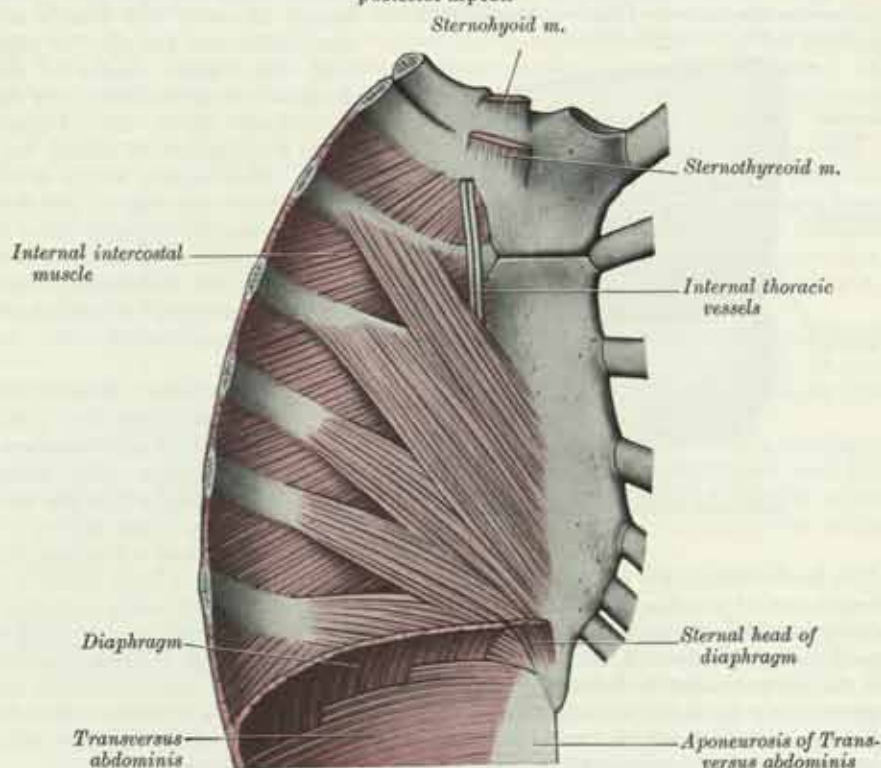
The ***Intercostales*** (fig. 576) are thin superimposed layers of muscle and tendinous fibres occupying the intercostal spaces. They are named from their surface relations—the *External intercostals* are most superficial and the *Intercostales intimi* are the innermost. The *Intercostales intimi* together with the *Subcostalis* and *Transversus thoracis* represent the deepest layer of muscle in the body wall in this region and are therefore sometimes grouped together under the term *Transversus thoracis*.

The ***Intercostales externi*** are eleven in number on each side. Their attachments extend from the tubercles of the ribs behind, where they are related to the posterior fibres of the superior costotransverse ligaments, almost to the cartilages of the ribs in front, where each is replaced by an aponeurotic layer named the *external (anterior) intercostal membrane*, which is continued forwards to the sternum. Each muscle arises from the lower border of one rib, and is inserted into the upper border of the rib below. In the lower two spaces they extend to the ends of the rib-cartilages, and in the upper two or three spaces they do not quite reach the ends of the ribs. They are thicker than the *Internal intercostals*, and their fibres are directed obliquely downwards and laterally on the back of the thorax, and downwards, forwards, and medially on the front.

The ***Intercostales interni*** are also eleven in number on each side. Their attachments commence anteriorly at the sternum, in the interspaces between the cartilages of the true ribs, and at the anterior extremities of the cartilages of the false ribs, and extend backwards as far as the angles of the ribs, where each is replaced by an aponeurotic layer named the *internal (posterior) intercostal membrane*, which is continuous posteriorly with the anterior fibres of the superior costotransverse ligament and anteriorly with the fascia intervening between the internal and external intercostal muscles. Each muscle arises from the floor of the costal groove and the corresponding costal cartilage, and is inserted into the upper border of the rib below. Their fibres are also directed obliquely, but nearly at right angles to those of the *External intercostal muscles*.

Actions.—The actions of the External and Internal intercostal muscles are very difficult to determine. Some believe that both groups act as elevators of the ribs whilst others have attributed the opposite action to the Internal intercostals. It has been shown however that impulses pass along the nerves to the External intercostals in inspiration and along those to the Internal intercostals in expiration.* It has also been maintained that the intercartilaginous part of the Internal intercostals act with the External intercostal muscles in inspiration. In addition the Intercostal muscles form strong elastic supports, which prevent the intercostal spaces being drawn in or bulged out during respiration. The anterior portions of the Internal intercostals probably have an additional function in keeping the sternocostal and

FIG. 575.—The left Transversus thoracis muscle, exposed and viewed from its posterior aspect.



Note that, in the interval between the sternal and the costal origins of the Diaphragm, the lower border of the Transversus thoracis lies edge to edge with the upper border of the Transversus abdominis.

interchondral joint-surfaces in apposition, the posterior portions of the External intercostals performing a similar function for the costovertebral joints.

The **Intercostales intimi** † are placed on the deep surfaces of the Internal intercostals and their fibres pass in the same direction. Each is attached to the inner surfaces of two adjoining ribs. Poorly developed, sometimes absent, in the upper intercostal spaces, the Intercostales intimi become gradually more extensive from above downwards. Below each covers the middle two-fourths of the intercostal space, and its posterior border is edge to edge with the lateral border of the corresponding Subcostalis muscle. The Intercostales intimi separate the intercostal vessels and nerves from the pleura (fig. 972).

Actions.—The Intercostales intimi act like the Internal intercostals.

The **Subcostales** consist of muscular and aponeurotic fasciculi, and are usually well developed only in the lower part of the thorax; each arises from the inner

* D. W. Bronk and L. K. Ferguson, *Amer. J. Physiol.*, **110**, 1935.

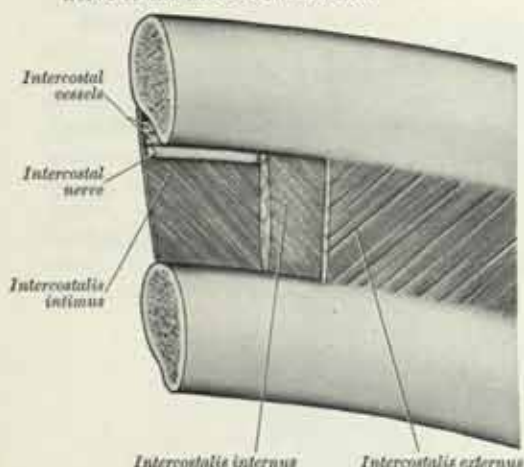
† These muscles were originally called Intracostales, and they are regarded by some anatomists merely as parts of the Internal intercostals. For a full description consult the following: T. Walmsley, *J. Anat., Lond.*, **50**, 1915 and F. Davies, R. J. Gladstone and E. P. Stibbe, *J. Anat., Lond.*, **66**, 1931.

surface of one rib near its angle, and is inserted into the inner surface of the second or third rib below. Their fibres run in the same direction as those of the Internal intercostals. Like the Intercostales intimi they intervene between the intercostal vessels and nerves and the pleura.

Actions.—The Subcostals depress the ribs.

The **Transversus thoracis (Sternocostalis)** is situated upon the inner surface of the front wall of the chest (fig. 575). It arises from the lower third of the posterior surface of the body of the sternum, from the posterior surface of the xiphoid process, and from the posterior surfaces of the costal cartilages of the lower three or four true ribs near their sternal ends. Its fibres diverge as they pass upwards and laterally, to be inserted by slips into the lower borders and inner surfaces of the costal

FIG. 576.—A dissection of a part of the thoracic wall, showing the position of the intercostal vessels and nerve to the intercostal muscles.



cartilages of the second, third, fourth, fifth, and sixth ribs. The lowest fibres of this muscle are horizontal, and are edge to edge with the highest fibres of the Transversus abdominis; the intermediate fibres are oblique, while the highest are almost vertical. This muscle varies in its attachments not only in different subjects but on opposite sides of the same subject. Like the Intercostales intimi and Subcostales, the Transversus thoracis separates the intercostal nerves from the pleura.

Actions.—The Transversus thoracis draws down the costal cartilages to which it is attached.

Nerve-supply.—All these muscles are supplied by the corresponding intercostal nerves.

The **Levatores costarum** (fig. 572), twelve in number on each side, are strong bundles which arise from the ends of the transverse processes of the seventh cervical and upper eleven thoracic vertebræ; they pass obliquely downwards and laterally, parallel with the posterior borders of the External intercostals, and each is inserted into the upper edge and outer surface of the rib immediately below the vertebra from which it takes origin, between the tubercle and the angle (*Levatores costarum breves*). Each of the four lower muscles divides into two fasciculi, one of which is inserted as above described; the other passes down to the second rib below its origin (*Levatores costarum longi*).

Nerve-supply.—The Levatores costarum are supplied by the lateral branches of the dorsal rami of the corresponding thoracic nerves.*

Actions.—The Levatores costarum being inserted near the fulcra of the ribs can have little or no elevating action on the ribs, but they may rotate the necks of the ribs in a forward direction; they are said to act as rotators and lateral flexors of the vertebral column.

The **Serratus posterior superior** is a thin, quadrilateral muscle, situated at the upper and posterior part of the thorax. It arises by a thin aponeurosis from the lower part of the ligamentum nuchæ, from the spines of the seventh cervical and upper two or three thoracic vertebræ and from the supraspinous ligament. Inclining downwards and laterally it is inserted, by four fleshy digitations, into the upper borders and outer surfaces of the second, third, fourth, and fifth ribs, a little beyond their angles. It lies superficial to the thoracolumbar fascia and is hidden by the Rhomboid muscles.

Nerve-supply.—The Serratus posterior superior is supplied by the second, third, fourth and fifth intercostal nerves.

Actions.—The Serratus posterior superior elevates the ribs to which it is attached.

The **Serratus posterior inferior** (fig. 594) is situated at the junction of the

* A. B. Morrison, *loc. cit.*

thoracic and lumbar regions : it is of an irregularly quadrilateral form, broader than the preceding muscle, and separated from it by a wide interval. It arises by a thin aponeurosis from the spines of the lower two thoracic and upper two or three lumbar vertebræ and from the supraspinous ligament ; this aponeurosis is intimately blended with the thoracolumbar fascia. Passing obliquely upwards and laterally, it becomes fleshy, and is inserted by four digitations into the inferior borders and outer surfaces of the lower four ribs, a little beyond their angles.

Nerve-supply.—The Serratus posterior inferior is supplied by the ventral rami of the ninth, tenth, eleventh and twelfth thoracic nerves.

Actions.—The Serratus posterior inferior draws the lower ribs downwards and backwards and thus elongates the thorax ; it also fixes the lower ribs, thus assisting the inspiratory action of the Diaphragm and resisting the tendency of the latter to draw the lower ribs upwards and forwards.

The **Diaphragm** (fig. 577) is a dome-shaped, musculo-fibrous septum which separates the thoracic from the abdominal cavity, its convex upper surface forming the floor of the former, and its concave under surface the roof of the latter. Its peripheral part consists of muscular fibres which take origin from the circumference of the thoracic outlet and converge to be inserted into a central tendon.

The muscular fibres may be grouped according to their origins into three parts—sternal, costal, and lumbar. The *sternal part* arises by two fleshy slips from the back of the xiphoid process ; the *costal part* from the inner surfaces of the cartilages and adjacent portions of the lower six ribs on each side, interdigitating with the Transversus abdominis (fig. 575) ; and the *lumbar part* from two aponeurotic arches, named the medial and lateral lumbocostal arches and from the lumbar vertebræ by two pillars or *crura*.

The *lateral lumbocostal arch* (*arcuate ligament*), which is a thickened band in the fascia covering the Quadratus lumborum, arches across the upper part of that muscle, and is attached, medially, to the front of the transverse process of the first lumbar vertebra, and, laterally, to the lower margin of the twelfth rib.

The *medial lumbocostal arch* (*arcuate ligament*) is a tendinous arch in the fascia covering the upper part of the Psoas major ; medially, it is continuous with the lateral tendinous margin of the corresponding crus, and is attached to the side of the body of the first or second lumbar vertebra ; laterally, it is fixed to the front of the transverse process of the first lumbar vertebra.

The *crura*.—At their origins the crura are tendinous in structure, and blend with the anterior longitudinal ligament of the vertebral column. The *right crus*, larger and longer than the left, arises from the anterior surfaces of the bodies and intervertebral discs of the upper three lumbar vertebræ, while the *left crus* arises from the corresponding parts of the upper two only. The medial tendinous margins of the crura meet in the median plane to form an arch across the front of the aorta, which is termed the *median arcuate ligament* ; it is often poorly defined.

From this series of origins the fibres of the Diaphragm converge to be inserted into the central tendon. The fibres arising from the xiphoid process are very short, and occasionally aponeurotic ; those from the medial and lateral lumbocostal arches, and more especially those from the ribs and their cartilages, are longer, and describe marked curves as they ascend and converge to their insertion. The fibres arising from the crura diverge as they ascend, the most lateral being directed upwards and laterally to the central tendon. The medial fibres of the right crus ascend on the left side of the œsophageal opening, and occasionally a fleshy fasciculus from the medial side of the left crus crosses the aorta and runs obliquely through the fibres of the right crus towards the vena caval opening, but this fasciculus is never continued upwards to help to bound the œsophageal passage on the right side.*

The *central tendon* of the Diaphragm is a thin but strong aponeurosis of closely interwoven fibres situated near the centre of the vault formed by the muscle, but somewhat closer to the front than to the back of the thorax, so that the posterior muscular fibres are the longer. It is placed immediately below the pericardium, with which it is partially blended. It is shaped somewhat like a trefoil leaf, and consists of three divisions or leaflets separated from one another by slight indentations. The middle leaflet has the form of an equilateral triangle, the apex of which is directed towards the xiphoid process of the sternum. The right and left leaflets

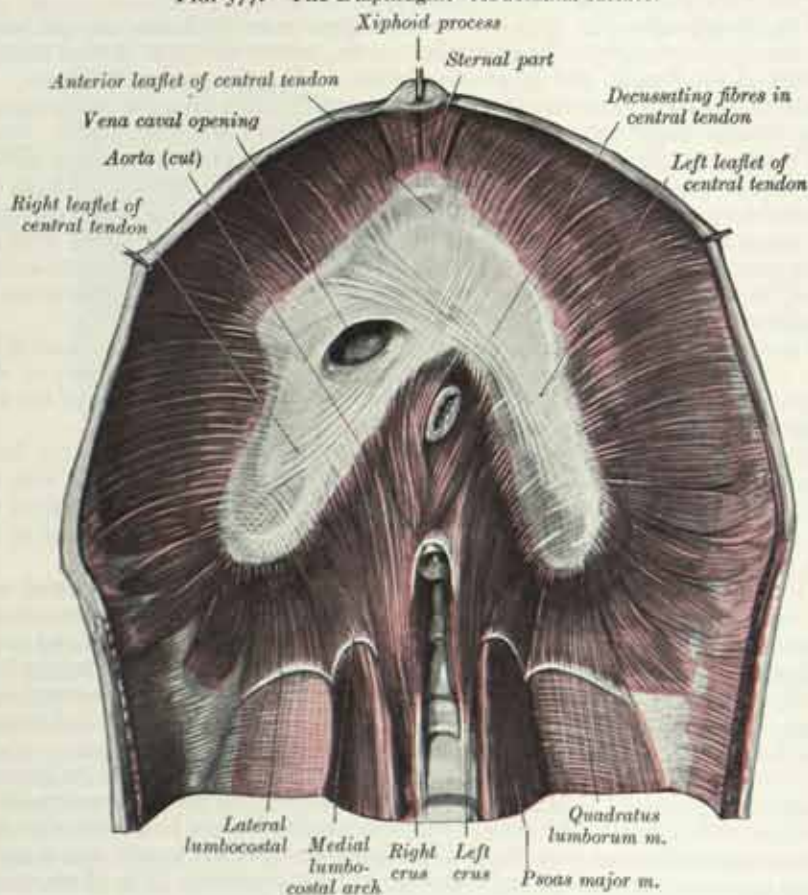
* A. Low, *J. Anat. and Physiol.*, 42, 1907.

are rather tongue-shaped and curve laterally and backwards, the left being a little narrower than the right. The central area of the tendon is occupied by four well-marked diagonal bands radiating from a thick central point like the bars of a St. Andrew's cross, and then expanding in a fan-shaped manner; the central point of decussation appears as a thick node of compressed tendinous strands situated in front of the œsophageal aperture, and to the left of the vena caval opening.*

Openings in the Diaphragm (fig. 577).—The Diaphragm is pierced by apertures for the passage of structures between the thorax and abdomen. Three large openings—the aortic, the œsophageal, and the vena caval—and a number of small ones are present.

The *aortic opening* is the lowest and most posterior of the large apertures; it lies

FIG. 577.—The Diaphragm. Abdominal surface.



at the level of the lower border of the twelfth thoracic vertebra, slightly to the left of the median plane. Strictly speaking, it is an osseo-aponeurotic opening between the vertebral column and the Diaphragm, and therefore behind the latter; occasionally some tendinous fibres from the medial parts of the crura pass behind the aorta, and convert the opening into a fibrous ring. The aortic opening transmits the aorta and the thoracic duct.†

The *œsophageal opening* is situated in the muscular part of the Diaphragm at the level of the tenth thoracic vertebra; it is elliptical in shape, and is 'formed by the splitting of the medial fibres of the right crus' (Low). It is placed above, in front, and a little to the left of the aortic opening, and transmits the œsophagus, the vagus nerves, and the œsophageal branches of the left gastric artery.

The *vena caval opening*, the highest of the three large openings, is situated about the level of the disc between the eighth and ninth thoracic vertebræ. It is quadri-

* D. M. Blair, *J. Anat.*, Lond., 57, 1922.

† It is stated frequently that the azygos vein passes through the aortic opening, but this description is not always strictly accurate (see p. 860).

lateral in form, and is placed at the junction of the right leaflet with the central area, so that its margins are tendinous. It transmits the inferior vena cava, the wall of which is adherent to the margin of the opening, and some branches of the right phrenic nerve.

There are two *lesser apertures* in each crus; of these one transmits the greater and the other the lesser splanchnic nerve. The gangliated trunks of the sympathetic usually enter the abdominal cavity behind the Diaphragm, deep to the medial lumbocostal arch. Openings for minute veins are frequently seen in the central tendon.

Blair (*loc. cit.*) described one of varying size, but of constant position, and present in ten out of twelve specimens he examined. It occurs in the angle between the left pair of bands as they diverge from the central point of decussation, and he suggested that the vein it transmits may represent the suprahepatic part of the left vitelline vein.

On each side there are two small areas where the muscular fibres of the Diaphragm are deficient and are replaced by areolar tissue. One between the sternal and costal parts transmits the superior epigastric branch of the internal thoracic artery and some lymph vessels from the abdominal wall and convex surface of the liver. The other, between the costal part and the fibres springing from the lateral lumbocostal arch, is less constant; when this interval exists, the upper and back part of the kidney is separated from the pleura by areolar tissue only.

Relations.—The upper surface of the Diaphragm is in relation with three serous membranes, viz. on each side with the pleura which separates it from the base of the corresponding lung, and on the middle leaflet of the central tendon with the pericardium, which intervenes between it and the heart. The central portion lies on a slightly lower level than the summits of the lateral portions, which are usually termed the *cupolae*. The greater part of the under surface is covered by the peritoneum. The right side is accurately moulded over the convex surface of the right lobe of the liver, the right kidney, and right suprarenal gland; the left over the left lobe of the liver, the fundus of the stomach, the spleen, the left kidney, and the left suprarenal gland.

Nerve-supply.—The Diaphragm is supplied by the phrenic nerve and the lower six or seven intercostal nerves, the latter being distributed to the peripheral part of the muscle.

Actions.—The Diaphragm is the principal muscle of inspiration, and presents the form of a dome concave towards the abdomen. The central part of the dome is tendinous, and the pericardium is attached to its upper surface; the circumferential part is muscular. During inspiration the lowest ribs are fixed, and from these and the crura the muscular fibres contract and draw downwards and forwards the central tendon with the attached pericardium. In this movement the curvature of the Diaphragm is scarcely altered, the dome moving downwards nearly parallel to its original position and pushing before it the abdominal viscera. The descent of the abdominal viscera is permitted by the extensibility of the abdominal wall, but the limit of this is soon reached. The central tendon, applied to the abdominal viscera, then becomes a fixed point for the action of the Diaphragm, the effect of which is to elevate the lower ribs and through them to push forwards the body of the sternum and the upper ribs. The right cupola of the Diaphragm, lying on the liver, has a greater resistance to overcome than the left, which lies over the stomach, but to compensate for this the right crus and the fibres of the right side generally are stronger than those of the left.

In all expulsive acts the Diaphragm is called into action to give additional power to each effort. Thus, before sneezing, coughing, laughing, crying, or vomiting, and previous to the expulsion of urine, or faeces, or of the fetus from the uterus, a deep inspiration takes place.

According to Whillis the fibres of the right crus exert a sphincteric action on the lower end of the œsophagus in man. The act of expiration, which immediately succeeds the act of swallowing, relaxes these fibres and allows the contents of the œsophagus to pass into the stomach.*

The height of the Diaphragm is constantly varying during respiration; it also varies with the degree of distension of the stomach and intestines and with the size of the liver. After a forced expiration the right cupola is on a level in front with the fourth costal cartilage, at the side with the fifth, sixth, and seventh ribs, and behind with the eighth rib; the left cupola is a little lower than the right. The absolute range of movement between deep inspiration and deep expiration averages in the

* J. Whillis, *J. Anat., Lond.*, 66, 1931.

male and female 30 mm. on the right side and 28 mm. on the left ; in quiet respiration the average movement is 12.5 mm. on the right side and 12 mm. on the left.

Radiographs show that the height of the Diaphragm in the thorax varies considerably with the position of the body. It stands highest when the body is horizontal and the patient on his back, and in this position it performs the largest respiratory excursions with normal breathing. When the body is erect the dome of the Diaphragm falls, and its respiratory movements become smaller. The dome falls still lower when the sitting posture is assumed, and in this position its respiratory excursions are smallest. When the body is horizontal and the patient on his side, the two halves of the Diaphragm do not behave alike. The uppermost half sinks to a level lower even than when the patient sits, and moves little with respiration ; the lower half rises higher in the thorax than it does when the patient is supine, and its respiratory excursions are much increased.

It appears that the position of the Diaphragm in the thorax depends upon three main factors, viz. : (1) the elastic retraction of the lung-tissue, tending to pull it upwards ; (2) the pressure exerted on its under surface by the viscera : this naturally tends to be a negative pressure, or downward suction, when the patient sits or stands, and a positive, or upward pressure, when he is lying down ; (3) the intra-abdominal tension due to the abdominal muscles. These muscles are in a state of contraction in the standing position but not in the sitting ; hence the Diaphragm is pushed up higher in the former position.

THE MOVEMENTS OF RESPIRATION

Two factors determine the nature of the movements that enable the lungs to expand in inspiration and to contract in expiration. Firstly, elastic tissue is present in the outer walls of the air-alveoli and there is a complete absence of muscle tissue in the structure of the lung. Secondly, when the glottis is open, the inner and outer surfaces of the air-alveoli are exposed to contrasting pressures ; the inner surfaces are subjected to atmospheric pressure, whereas the outer surfaces are related to the negative pressure in the pleural sac. As a result the active movements of respiration depend on alterations in the capacity of the thoracic cavity produced by movements of its walls. The movements of the ribs modify the anteroposterior and transverse diameters of the thorax, while the vertical measurements are affected by the ascent and descent of the Diaphragm.

The range and character of the movements of the thoracic parietes exhibit very striking individual variations, which may be dependent on the conformation of the thoracic skeleton, on habit or occasionally on other factors, and this extreme variability must be borne in mind, when the movements are being analysed in any particular subject.

In *quiet inspiration* the first rib remains relatively fixed as a rule and there is little alteration in the position of the upper border of the manubrium sterni. The succeeding ribs are elevated and everted by the Intercostal and the Levatores costarum muscles. As a result of the movements of the second to the seventh ribs the transverse diameter of the thorax is increased and at the same time the body of the sternum is thrust forwards to a slight extent (p. 477), increasing the anteroposterior diameter. The corresponding movements of the lower ribs result in the elevation of the costal margin and produce a greater effect on the transverse than on the anteroposterior diameter. In an average case the right cupola of the Diaphragm descends to the level of the intervertebral disc between T. 10 and T. 11 or to the upper border of T. 11, while its left cupola descends to the level of the disc between T. 11 and T. 12.

In *quiet expiration* air is expelled owing partly to the elastic recoil of the chest wall and partly to the tonus of the muscles of the abdominal wall, which, acting through the abdominal viscera, exert an upward pressure on the Diaphragm.

In *deep inspiration* the movements just described are increased and additional muscles are called into play. The first rib is elevated by the Scaleni, anterior et medius, and indirectly, through the clavicle and the costoclavicular ligament, by the Sternomastoid muscle. This movement is necessarily accompanied by an upward and forward movement of the manubrium sterni and a slight accentuation of the sternal angle. The excursions of the succeeding ribs are appreciably increased and the forward movement of the body of the sternum is correspondingly greater. Elevation of the eighth, ninth and tenth ribs (p. 477) leads to a widening of the

infrasternal angle and an increase in the transverse diameter of the lower part of the thoracic cavity and the upper part of the abdominal cavity. In addition, the antero-posterior diameter of the abdominal cavity is diminished in and adjoining the median plane but is increased in its lateral part. The effect of these changes is to provide additional space in the abdominal cavity and so to facilitate the action of the Diaphragm. The twelfth rib, however, is fixed by the *Quadratus lumborum* muscle, so that the Diaphragm is able to exert a more powerful downward thrust on the abdominal viscera. In addition, the *Erectores spinæ* come into action and the concavity of the thoracic part of the vertebral column is diminished, a movement which results in a slight increase in the width of the intercostal spaces and allows the ribs a greater range of movement. As the result of all these factors the cavity of the thorax is enlarged in all its diameters.

In *forced inspiration* the scapulæ are elevated and fixed by the *Trapezius*, *Levator Scapulæ* and *Rhomboid* muscles so that the *Serratus anterior* and *Pectoralis minor* muscles are able to act on the ribs from which they take origin. The action of the *Erectores spinæ* is appreciably augmented. This type of inspiration is called forth when there is any obstruction to air-intake and every available muscle is then brought into action. The right cupola of the Diaphragm descends to the level of T. 11; while the left cupola may reach the level of the body of T. 12, although it frequently fails to descend beyond the disc between T. 11 and T. 12.

In *deep* and in *forced expiration* additional expulsive factors are provided by the strong contraction of the muscles of the abdominal wall and by the *Latissimus dorsi* muscles, which contract suddenly and energetically with such efforts as coughing and sneezing.

It may be noted that individuals may be trained to use the Diaphragm independently of or in association with the other muscles of inspiration. In these cases the Diaphragm usually descends to a lower level when used independently, despite the fact that when all the muscles of inspiration are brought into action the volume of air-intake is increased by as much as 40 per cent., or even more.

Applied Anatomy.—The changes in the height of the Diaphragm during alterations in posture explain why patients suffering from severe dyspnoea are most comfortable and least short of breath when they sit up. In unilateral disease of the pleura or lungs interference with the position or movement of the Diaphragm can generally be observed on X-ray examination. Middleton,* by estimating the vital capacity in cases where the action of the Diaphragm was impaired by thoracic wounds or empyema, concluded that the normal diaphragmatic contraction is responsible for 60 per cent. of the respiratory exchange in deep breathing.

IV. THE MUSCLES OF THE ABDOMEN

The muscles of the abdomen may be divided into anterolateral and posterior groups.

1. THE ANTEROLATERAL MUSCLES

Obliquus externus.	Transversus.
Obliquus internus.	Rectus.
	Pyramidalis.

The **superficial fascia** of the abdomen consists, over the greater part of the abdominal wall, of a single layer containing a variable amount of fat; but near the groin the fascia is easily divisible into two layers, between which are found the superficial vessels, nerves, and inguinal lymph glands.

The superficial layer of the fascia is thick, areolar in texture, and contains in its meshes a varying quantity of fat. Below, it passes over the inguinal ligament, and is continuous with the superficial fascia of the thigh. In the male this layer is continued over the penis and outer surface of the spermatic cord to the scrotum. As it passes to the scrotum it changes its characteristics, becoming thin, destitute of adipose tissue, and of a pale reddish colour; in the scrotum it acquires some involuntary muscular fibres and forms the *dartos* muscle. From the scrotum it may be traced backwards into continuity with the superficial fascia of the perineum. In the female it is continued from the abdomen into the labia majora.

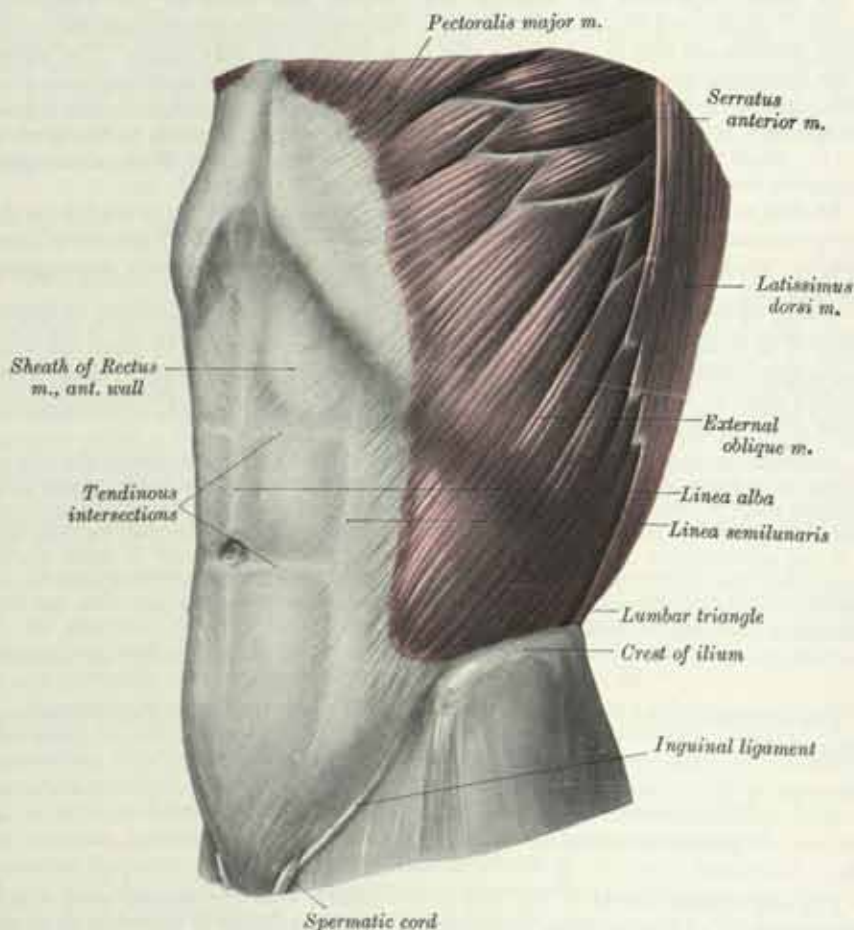
The deep layer of the fascia, thinner and more membranous than the superficial layer, contains a considerable quantity of elastic fibres. It is loosely connected by

* *Amer. J. Med. Sci.*, 166, 1923.

areolar tissue to the aponeurosis of the External oblique muscle, but in the median plane it is more intimately adherent to the linea alba and to the symphysis pubis, and is prolonged on to the dorsum of the penis, forming the *fundiform ligament* (fig. 580); above, it is continuous with the superficial fascia over the rest of the trunk; below and laterally, it blends with the fascia lata of the thigh a little below and parallel with the inguinal ligament (fig. 579); below and medially, it is continued over the penis and spermatic cord to the scrotum, and from there may be traced backwards into continuity with the membranous layer of the superficial fascia of the perineum (p. 607). In the female it is continued into the labia majora and thence to the fascia of the perineum.

The **Obliquus externus abdominis** (fig. 578), situated on the lateral and

FIG. 578.—The left Obliquus externus abdominis.



anterior parts of the abdomen, is the largest and the most superficial of the three flat muscles in this region. It arises, by eight fleshy slips, from the external surfaces and inferior borders of the lower eight ribs; these slips interdigitate with the slips of origin of the Serratus anterior and Latissimus dorsi, and are arranged in an oblique line which runs downwards and backwards, the upper ones being attached close to the cartilages of the corresponding ribs, the lowest to the apex of the cartilage of the last rib, the middle ones to the ribs at some distance from their cartilages. From these attachments the fleshy fibres diverge as they pass to their insertions. Those from the lower two ribs pass nearly vertically downwards, and are inserted into the anterior half or more of the outer lip of the ventral segment of the iliac crest (p. 397); the middle and upper fibres, directed downwards and forwards, end in an aponeurosis, opposite a line drawn vertically from the ninth costal cartilage to a little below the level of the umbilicus, and then inclining laterally to the anterior superior iliac spine. None of the fleshy fibres of the muscle extend downwards beyond a line drawn from

the anterior superior iliac spine to the umbilicus. The posterior border of the muscle is free (fig. 594).

The *aponeurosis* of the External oblique muscle is a thin but strong membranous structure, the fibres of which are directed downwards and medially. In the median plane its fibres end in the *linea alba* (fig. 578), a tendinous raphe which stretches from the xiphoid process to the symphysis pubis. There it is continuous with the aponeurosis of the corresponding muscle of the opposite side and the two together cover the front of the abdomen. Above and laterally, it is covered by, and gives origin to, the lower fibres of the Pectoralis major; below, its fibres are closely aggregated together, and extend obliquely across from the anterior superior iliac spine to the pubic tubercle and the pecten pubis.

The margin of that portion of the aponeurosis which extends between the anterior superior iliac spine and the pubic tubercle is a thick band, folded backwards upon itself to present a grooved upper surface, and continuous below with the fascia lata of the thigh; it is called the *inguinal ligament*. A small portion is reflected from the medial part of the inguinal ligament, and is attached to the pecten pubis; it is called the *lacunar ligament*. From the attachment of the latter a few fibres pass upwards and medially behind the superior crus of the superficial inguinal ring to the linea alba; they diverge as they ascend, and form a thin triangular fibrous band, which is called the *reflected part of the inguinal ligament* (fig. 585).

The complete insertion of the muscle can now be summarised. The highest fibres are inserted into the xiphoid process; the succeeding fibres into the linea alba, the upper border of the pubic symphysis and the adjoining part of the pubic crest, the pubic tubercle and the adjoining part of the pecten pubis; and the lowest fibres into the anterior superior iliac spine and the anterior two-thirds of the outer lip of the ventral segment of the iliac crest.

Nerve-supply.—The External oblique muscle is supplied by the ventral rami of the lower six thoracic nerves.

Certain parts of the aponeurosis of the External oblique muscle require more detailed consideration.

The **superficial inguinal ring** (figs. 579, 580) is an interval in the aponeurosis, just above and lateral to the crest of the pubis. The aperture is somewhat triangular in form, and its long axis is oblique, corresponding with the course of the fibres of the aponeurosis. It measures from base to apex about 2.5 cm., and across the base about 1.25 cm. Its base is formed by the crest of the pubis, and its sides by the margins of the opening in the aponeurosis, which are called the *crura of the ring*; above, the crura are connected by a series of curved *intercrural fibres*. The lateral crus of the ring is the stronger, and is formed by that portion of the inguinal ligament which is inserted into the pubic tubercle; it is curved so as to form a kind of groove, upon which, in the male, the spermatic cord rests. The medial crus is a thin, flat band, the fibres of which are attached to the front of the symphysis pubis, and interlace with the fibres of the opposite medial crus.

The superficial inguinal ring gives passage to the spermatic cord and ilio-inguinal nerve in the male, and to the round ligament of the uterus and the ilio-inguinal nerve in the female; it is much larger in men than in women, on account of the size of the spermatic cord. If the skin of the scrotum is invaginated in an upward and lateral direction the spermatic cord can be followed up to the superficial inguinal ring. If the examining finger is then directed *backwards*, the crura of the ring can be recognised and the size of the ring determined.

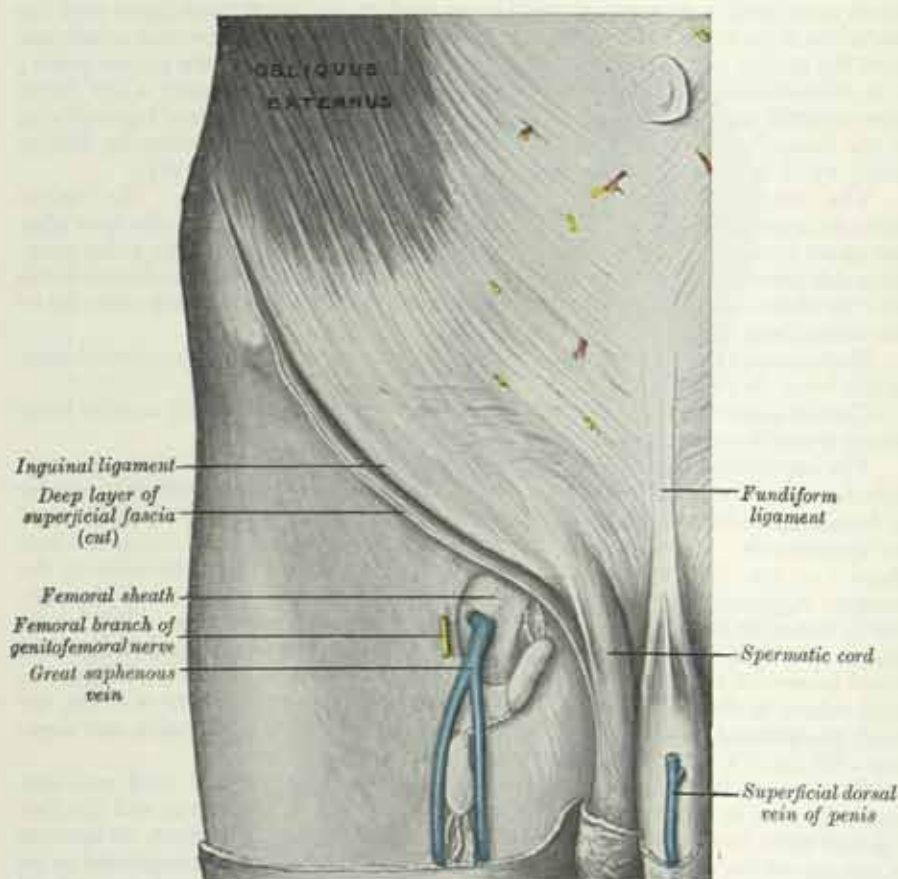
The **intercrural fibres** are curved, tendinous fibres which arch across the lower part of the aponeurosis of the External oblique muscle, describing curves with the convexities downwards. They have received their name from the fact that they stretch across between the two crura of the superficial inguinal ring. When well developed they can be traced upwards and medially from the middle third of the inguinal ligament, the lower fibres crossing the apex of the superficial inguinal ring. The intercrural fibres increase the strength of the lower part of the aponeurosis, and tend to prevent the divergence of the crura from each other; they are more strongly developed in the male than in the female. As they pass across the superficial inguinal ring they are connected together by delicate fibrous tissue, forming what is called the **external spermatic fascia**. This fascia is continued down as a tubular prolongation around the spermatic cord and testis, and forms the outermost of the coverings which enclose them. The superficial inguinal ring is seen as a distinct

aperture only after the continuity between this fascia and the aponeurosis of the External oblique muscle has been severed.

The **inguinal ligament** (figs. 580, 581) is the lower border of the aponeurosis of the External oblique muscle, and stretches from the anterior superior iliac spine to the pubic tubercle. Its general direction is convex downwards towards the thigh, and it is continuous with the fascia lata. Its lateral one-half is rounded, and oblique in direction; its medial one-half gradually widens at its attachment to the pubis, is more horizontal in direction, and supports the spermatic cord.

The **lacunar ligament (pectineal part of the inguinal ligament)** (fig. 581) is that portion of the aponeurosis of the External oblique muscle which passes back-

FIG. 579.—A superficial dissection of the groin and the lower part of the anterior abdominal wall. Right side.



wards and laterally from the medial part of the inguinal ligament, and is attached to the medial end of the pecten pubis. It is of a triangular form, and is almost horizontal in plane when the body is in the erect posture; it is a little larger in the male than in the female, and measures about 2 cm. from base to apex. Its base, directed laterally, is concave and thin, and forms the medial boundary of the femoral ring; its apex corresponds to the pubic tubercle. Its posterior margin is attached to the pecten pubis, and is continuous with the pectineal fascia; its anterior margin is continuous with the inguinal ligament. Its surfaces are directed upwards and downwards.

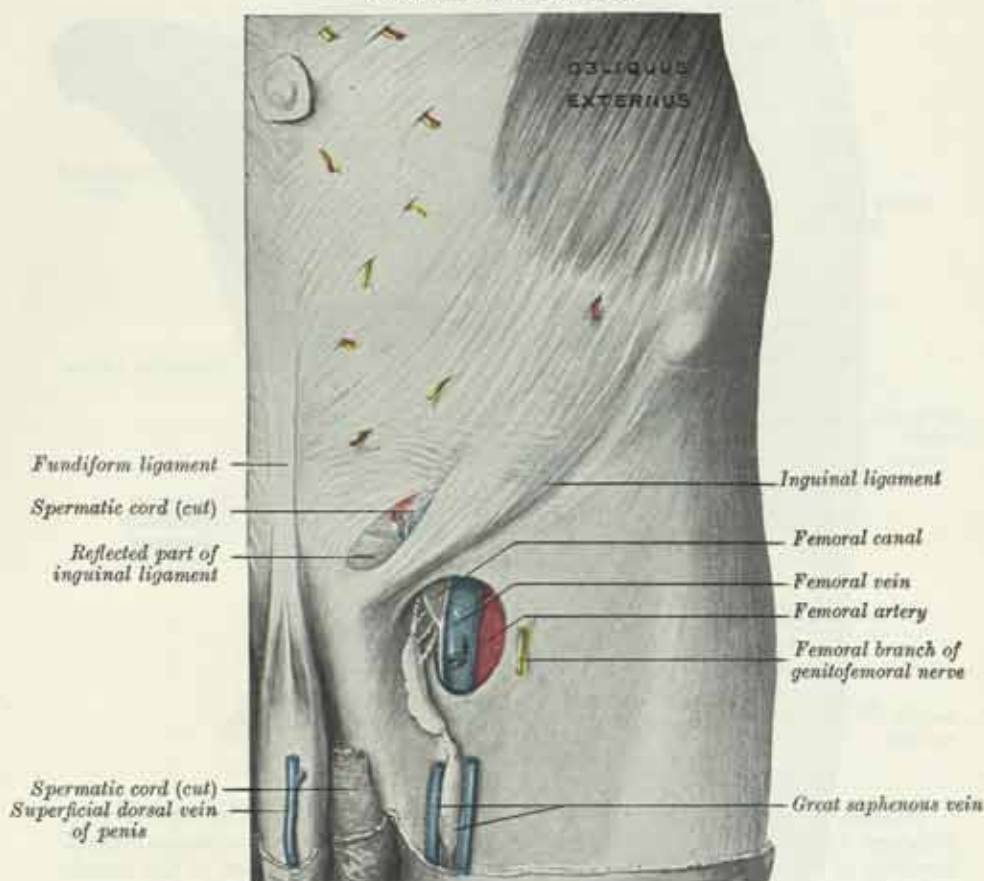
The **reflected part of the inguinal ligament** (figs. 580, 585) is formed by an expansion from the lacunar ligament and the lateral crus of the superficial inguinal ring. It passes medially behind the spermatic cord, expands into a triangular band behind the medial crus of the superficial inguinal ring and in front of the conjoint tendon; its fibres interlace with those of the opposite ligament at the linea alba.

The **pectineal ligament (ligament of Cooper)**.—This is a strong fibrous band, first described by Sir Astley Cooper. It extends laterally from the base of the lacunar

ligament (fig. 581) along the pecten pubis to which it is attached. It is strengthened by the pectineal fascia, and by a lateral expansion from the lower attachment of the linea alba (adminiculum lineæ albæ) (p. 599).

The **Obliquus internus abdominis** (fig. 582), which lies under cover of the External oblique, is a thinner and less bulky muscle. It arises, by fleshy fibres, from the lateral two-thirds of the grooved upper surface of the inguinal ligament, from the anterior two-thirds of the intermediate line of the ventral segment of the iliac crest, and from the thoracolumbar fascia (fig. 571). The posterior fibres ascend almost vertically, and are inserted into the inferior borders of the lower three ribs, and are there continuous with the Internal intercostals. The fibres arising from the

FIG. 580.—A superficial dissection of the groin and the lower part of the anterior abdominal wall. Left side.



inguinal ligament, paler in colour than the others, arch downwards and medially across the spermatic cord in the male and the round ligament of the uterus in the female. Becoming tendinous they are inserted, conjointly with the corresponding part of the aponeurosis of the Transversus abdominis, into the crest of the pubis and the medial part of the pecten pubis, forming what is known as the *conjoint tendon*. The rest of the fibres of the Internal oblique muscle diverge and end in an aponeurosis which gradually broadens from below upwards. The greater part of this aponeurosis splits at the lateral border of the Rectus abdominis into two lamellæ which ensheathe this muscle, and reunite at the linea alba. The anterior layer of this sheath blends with the aponeurosis of the External oblique muscle; the posterior layer fuses with the aponeurosis of the Transversus abdominis, and its upper part is attached to the cartilages of the seventh, eighth and ninth ribs.

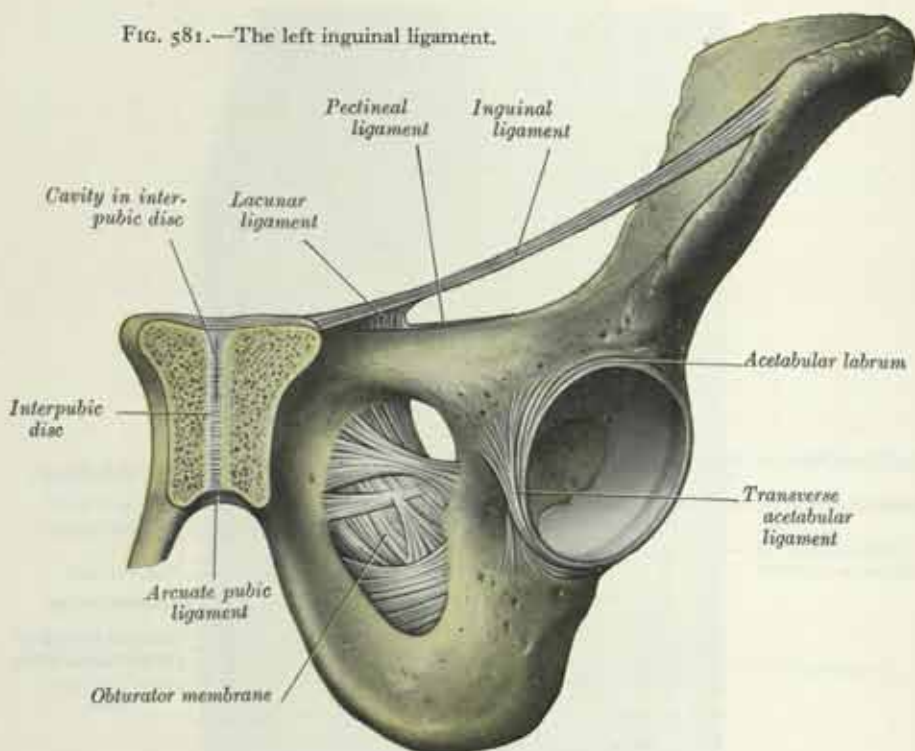
Nerve-supply.—The Internal oblique muscle is supplied by the ventral rami of the lower six thoracic and the first lumbar nerves.

The **Cremaster** (fig. 584) is a thin muscular layer composed of a number of fasciculi which arise from the middle of the inguinal ligament, where its fibres are

continuous with those of the Internal oblique and also occasionally with the Transversus. It passes along the lateral side of the spermatic cord, and descends with it through the superficial inguinal ring upon the anterior and lateral surfaces of the cord, where it forms a series of loops of varying thickness and length. Short above, the loops become successively longer, the longest reaching as far as the tunica vaginalis, into which a few are inserted. These loops are united together by areolar tissue, and form a thin covering over the cord and testis, named the *cremasteric fascia*. The fibres ascend along the medial and posterior surfaces of the cord, and are inserted by a small pointed tendon into the tubercle and crest of the pubis and into the front of the sheath of the Rectus abdominis.

Nerve-supply.—The Cremaster is supplied by the genital branch of the genito-femoral nerve (L. 1 and 2).

FIG. 581.—The left inguinal ligament.



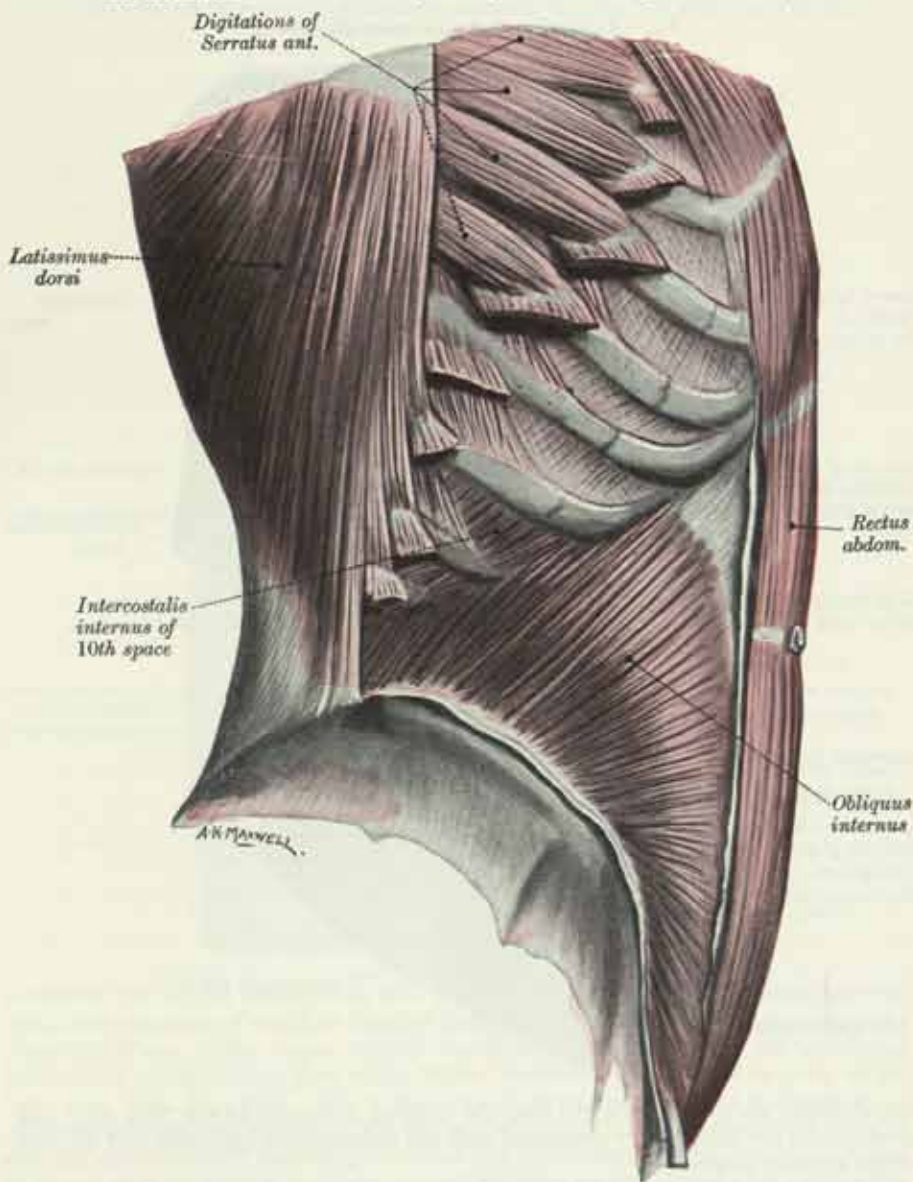
Action.—The Cremaster pulls up the testis towards the superficial inguinal ring. Although its fibres are transversely striated, it is not usually under voluntary control. Stroking of the medial side of the thigh evokes a reflex contraction of the muscle and this (cremasteric) reflex is much more active in the child than in the adult.

The **Transversus abdominis** (fig. 583), so called from the direction of its fibres, is the innermost of the flat muscles of the abdominal wall, being situated deep to the Internal oblique. It arises by fleshy fibres from the lateral one-third of the inguinal ligament, from the anterior two-thirds of the inner lip of the ventral segment of the iliac crest, from the thoracolumbar fascia as it extends between the iliac crest and the twelfth rib, and from the inner surfaces of the cartilages of the lower six ribs, interdigitating with the Diaphragm (fig. 575). The muscle ends in an aponeurosis, the lower fibres of which curve downwards and medially, and are inserted, together with those of the aponeurosis of the Internal oblique muscle, into the crest and pecten of the pubis, forming the conjoint tendon. The rest of the aponeurosis passes horizontally to the median plane, and is inserted into the linea alba: its upper three-fourths lie behind the Rectus abdominis and blend with the posterior lamella of the aponeurosis of the Internal oblique muscle; its lower one-fourth is in front of the Rectus. The upper muscular fibres of the Transversus abdominis are continued medially behind the Rectus (fig. 583) and the posterior lamella of the aponeurosis of the Internal oblique. Near the xiphoid process they reach to

within 2 or 3 cm. of the linea alba. The muscular fibres of the Transversus run into the aponeurosis along a line which is concave medially (fig. 583), the aponeurosis being widest opposite the origin of the muscle from the thoracolumbar fascia.

The *conjoint tendon* (*falx inguinalis*) of the Internal oblique and Transversus (fig. 585, 586) is mainly formed by the lower part of the aponeurosis of the Transversus.

FIG. 582.—Dissection of the muscles of the side of the trunk. The External oblique muscle has been removed to show the Internal oblique, but its digitations from the ribs have been preserved. The sheath of the Rectus has been opened and its anterior wall removed. (From Quain's *Anatomy*, XI. Edition.)

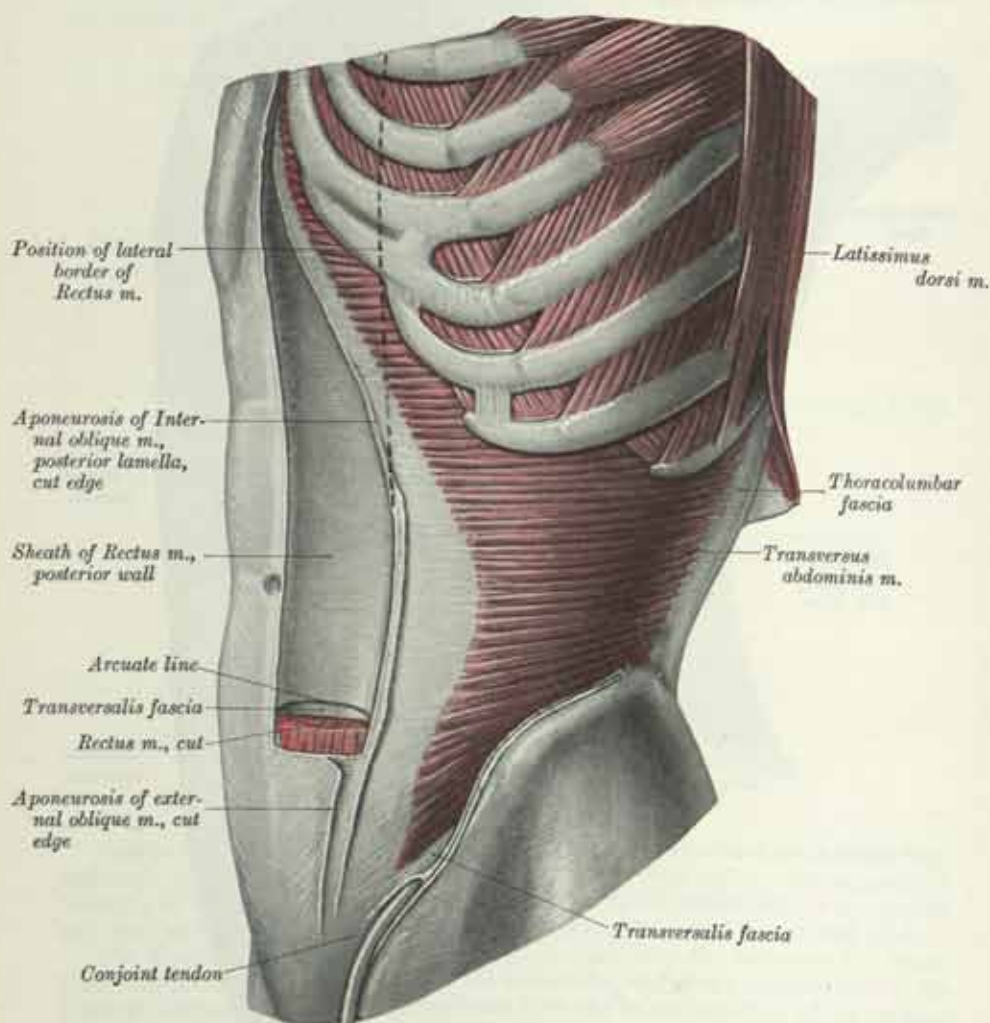


and is inserted into the crest and pecten of the pubis; it descends behind the superficial inguinal ring, thus serving to protect from behind what would otherwise be a weak point in the abdominal wall. The attachment to the pecten pubis is frequently absent. Medially the conjoint tendon is directly continuous with the anterior wall of the sheath of the Rectus abdominis. Laterally, the conjoint tendon may be continuous with an inconstant ligamentous band, named the *interfoveolar ligament*, which sometimes connects the lower margin of the Transversus to the superior ramus of the pubis; it occasionally contains a few muscular fibres.

Nerve-supply.—The Transversus abdominis is supplied by the ventral rami of the lower six thoracic and the first lumbar nerves.

The **Rectus abdominis** (fig. 587) is a long flat muscle, broader above than below, which extends along the whole length of the front of the abdomen, and is separated from its fellow of the opposite side by the linea alba. It arises by two tendons; the lateral and larger is attached to the crest of the pubis; the medial interlaces with its fellow of the opposite side and is connected with the ligamentous fibres covering the front of the symphysis pubis. The muscle is inserted by three slips of unequal size into the cartilages of the fifth, sixth, and seventh ribs; the most

FIG. 583.—The left Transversus abdominis.

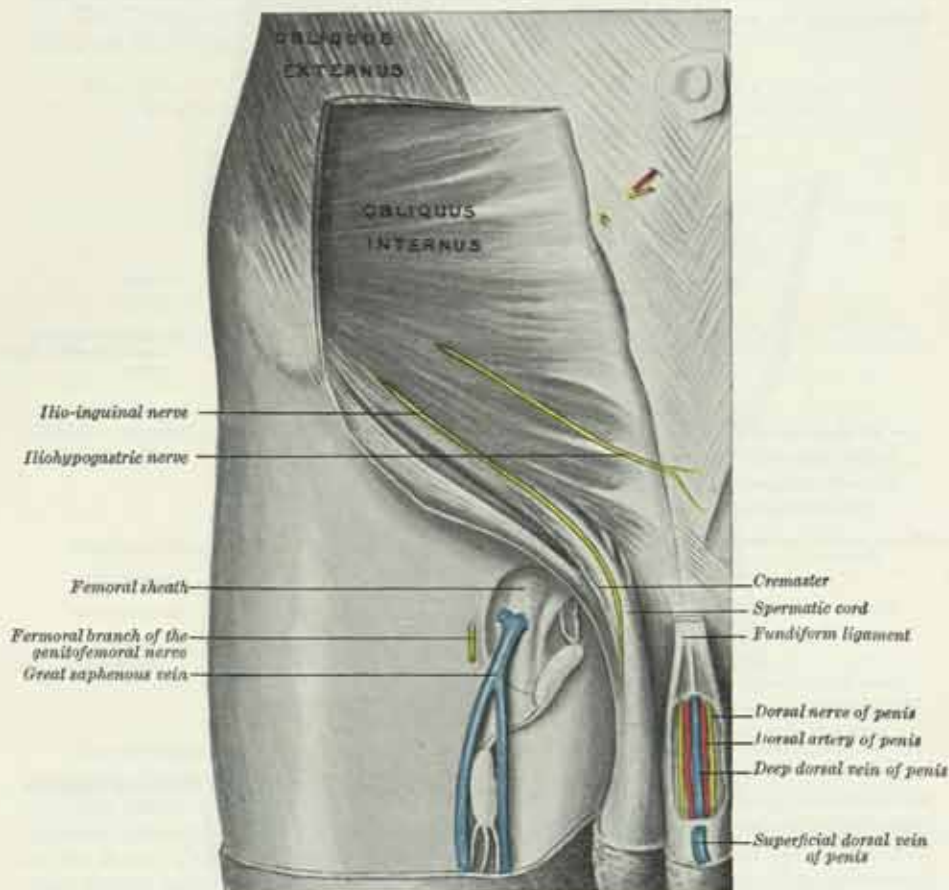


lateral fibres are usually inserted into the anterior extremity of the fifth rib; the most medial are occasionally connected with the costoxiphoid ligaments and the side of the xiphoid process.

The rectus is intersected by three fibrous bands, named *tendinous intersections*; one is usually situated opposite the umbilicus, another opposite the free end of the xiphoid process, and a third about midway between the xiphoid process and the umbilicus. These intersections pass transversely or obliquely across the muscle in a zigzag course; they rarely extend completely through its substance and may pass only halfway across it; they are intimately adherent to the anterior lamina of the sheath of the muscle. Sometimes one or two incomplete intersections are present below the umbilicus. All these intersections represent intersegmental tissue and are evidence of the segmental origin of the muscle.

The Rectus abdominis is enclosed in a *sheath* (figs. 578, 583, 588) formed by the aponeuroses of the Obliqui and Transversus, which are arranged as follows: at the lateral margin of the Rectus, the aponeurosis of the Internal oblique divides into two lamellæ, one of which passes in front of the Rectus, blending with the aponeurosis of the External oblique, the other, behind it, blending with the aponeurosis of the Transversus, and these, joining again at the medial border of the Rectus, reach the linea alba. This arrangement of the aponeuroses exists from the costal margin to midway between the umbilicus and symphysis pubis, where the

FIG. 584.—A dissection of the regions shown in fig. 579, but with a part of the Obliquus externus removed.



posterior wall of the sheath ends in a curved margin, named the *arcuate line* (fig. 587), the concavity of which is directed downwards. As already stated (p. 594) the muscular fibres of the upper part of the Transversus abdominis are continued behind the corresponding part of the Rectus abdominis to within 2 or 3 cm. of the linea alba (figs. 583, 588). Below the level of the arcuate line the aponeuroses of all three muscles pass in front of the Rectus; those of the Transversus and Internal oblique are intimately fused together, but the aponeurosis of the External oblique is bound to them merely by loose connective tissue except in and near the median plane; behind, this part of the Rectus is separated from the peritoneum by the transversalis fascia (fig. 589). Since the aponeuroses of the Internal oblique and Transversus only reach as high as the costal margin it follows that above that level the sheath of the Rectus is deficient posteriorly, the muscle resting directly on the cartilages of the ribs; the front of this part of the Rectus is covered merely by the aponeurosis of the External oblique muscle.

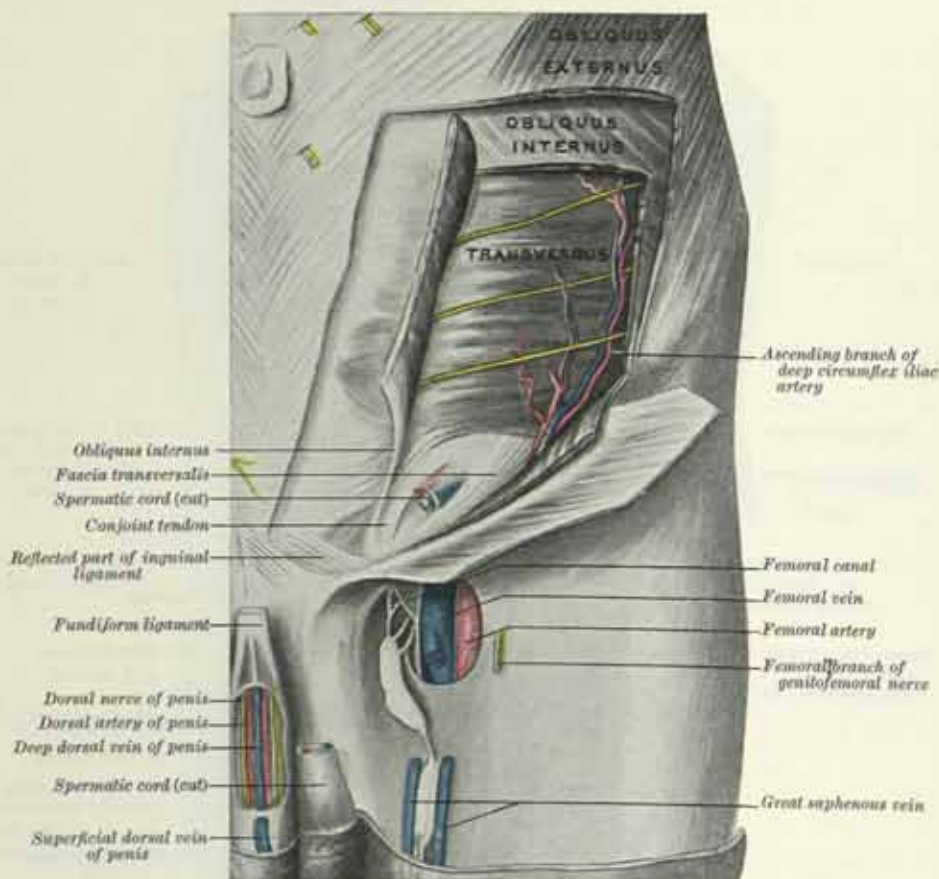
The medial border of the muscle is closely related to the linea alba: its lateral border is marked on the surface of the anterior abdominal wall by a curved groove,

termed the *linea semilunaris*, which extends from the tip of the ninth costal cartilage to the pubic tubercle. It is readily seen in a muscular subject even when the muscle is not actively contracting.

Nerve-supply.—The Rectus abdominis is supplied by the ventral rami of the lower six or seven thoracic nerves.

The **Pyramidalis** (fig. 587) is a triangular muscle, placed at the lower part of the abdomen, in front of the Rectus abdominis and within the sheath of that muscle. It arises by tendinous fibres from the front of the pubis and from the ligamentous

FIG. 585.—A dissection of the regions shown in fig. 580, but with portions of the Obliqui externus et internus removed.



fibres in front of the symphysis; the fleshy portion of the muscle passes upwards, diminishing in size as it ascends, and ends in a pointed extremity which is inserted into the linea alba midway between the umbilicus and pubis, but may extend to a higher level. This muscle may be larger on one side than on the other, or may be wanting on one or both sides.

Besides the Rectus and Pyramidalis, the sheath of the Rectus contains the superior and inferior epigastric vessels, and the terminal portions of the lower intercostal nerves.

Nerve-supply.—The Pyramidalis is supplied by the subcostal nerve (T. 12).

Actions.—The anterolateral group of abdominal muscles provide a firm but elastic wall to retain the abdominal viscera in position and to oppose the action of gravity on them in the erect and sitting postures. This function is principally dependent on the normal tonus of the oblique muscles, especially the Internal oblique.

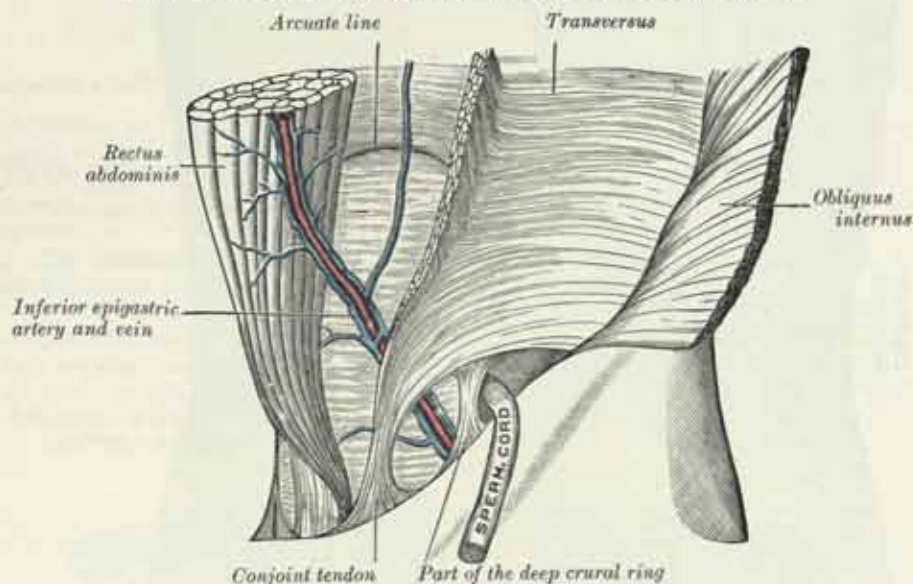
When the thorax and pelvis are fixed, the active contraction of these muscles exercises a compressing force on the abdominal viscera. In this way they play an important part in expiration, and they assist in expelling faeces from the rectum, the

fœtus from the uterus, the urine from the bladder and the contents of the stomach in vomiting. This action is mainly due to the oblique muscles. They tense the rectus sheath whilst the Rectus abdominis itself plays a minor rôle. If the pelvis and vertebral column are fixed, the external oblique muscles aid further in expiration by depressing and compressing the lower part of the thorax.

When the pelvis is fixed, the Recti and to a lesser extent the Obliqui of the two sides, acting together, bend the trunk forwards and flex the lumbar part of the vertebral column; when the thorax is fixed, they draw the front of the pelvis upwards and have the same effect as before on the vertebral column.* If the muscles of only one side act, the trunk is bent towards that side. In addition, the External oblique muscle tends to turn the front of the abdomen towards the opposite side, and the Internal oblique turns it to the same side.

The Transversus acts only on the abdominal contents and has no appreciable effect on the vertebral column.

FIG. 586.—The lower part of the anterior abdominal wall showing the relations of the spermatic cord at the deep inguinal ring. Modified from Braune.



The Pyramidalis is a tensor of the linea alba, but the advantage of, or the necessity for, this action is by no means clear.

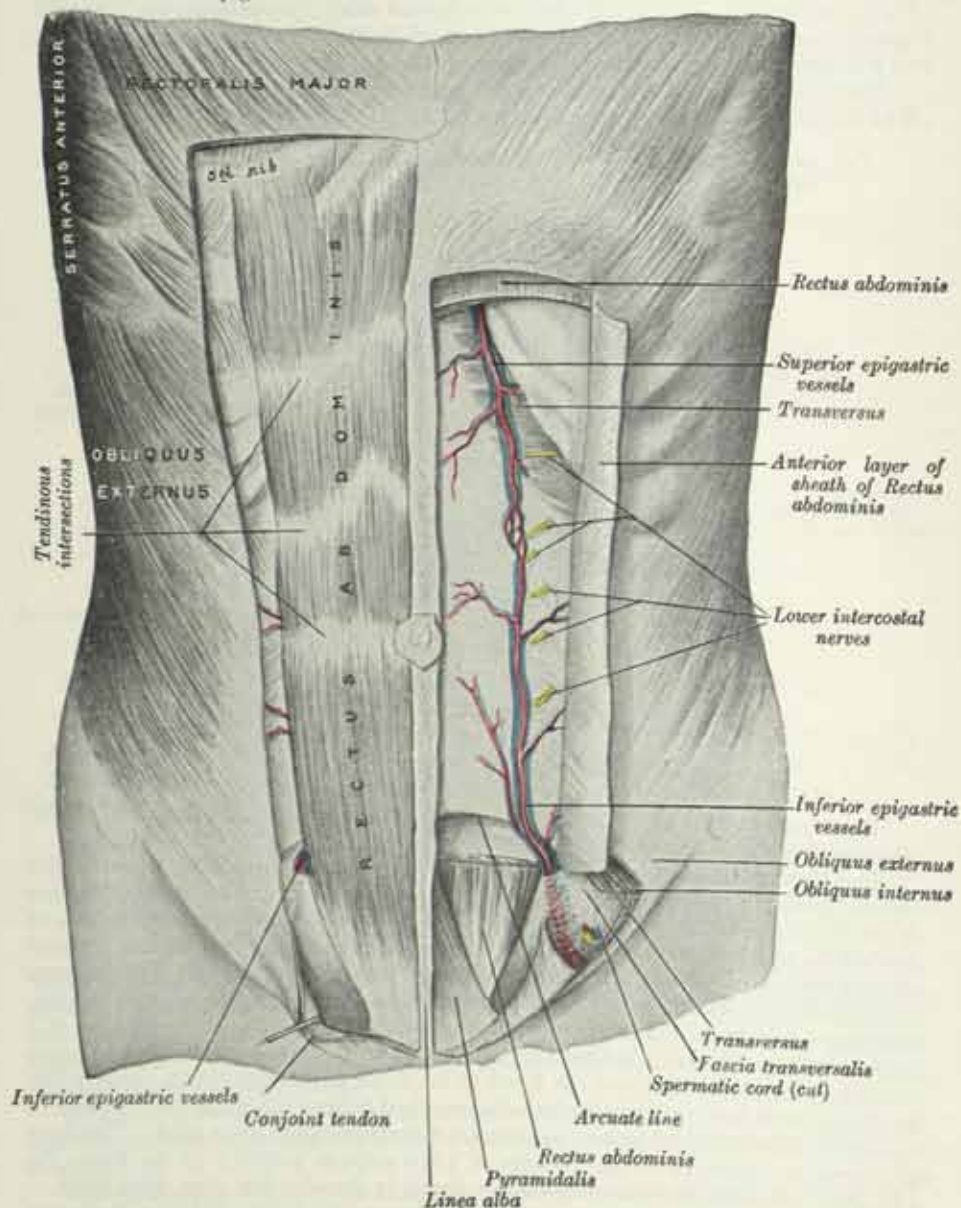
The **linea alba** (figs. 578, 588) is a tendinous raphe stretching between the xiphoid process and the symphysis pubis. It is placed between the medial borders of the Recti, and is formed by the interlacement of the fibres of the aponeuroses of the Obliqui and Transversi. It is narrow below, corresponding to the linear interval existing between the Recti; but broader above, where these muscles diverge from each other. In its infra-umbilical portion, it is visible in life only in young, muscular subjects, but its supra-umbilical portion can usually be recognised as a shallow groove. Its lower end has a double attachment—its superficial fibres passing in front of the medial heads of the Recti to the front of the symphysis pubis, while its deeper fibres form a triangular lamella, attached behind the Recti to the posterior surface of the crest of the pubis, and named the *adminiculum lineæ albæ*. The linea alba presents apertures for the passage of a few minute vessels; in the fœtus the umbilicus transmits the umbilical vessels, but it is closed a few days after birth.

The **transversalis fascia** is a thin membrane which lies between the inner surface of the Transversus muscle and the extraperitoneal fat. It forms part of the general layer of fascia lining the abdominal parietes, and is continuous with the iliac and pelvic fasciæ. In the inguinal region it is thick and dense in structure, and is joined by fibres from the aponeurosis of the Transversus, but it becomes thin as it ascends to the Diaphragm, and blends with the fascia covering the under surface of this muscle. Behind, it is lost on the surface of the thoracolumbar fascia, with

* W. F. Floyd and P. H. S. Silver, *J. Anat., Lond.*, 84, 1950.

which it blends. Below, it has the following attachments: posteriorly, to the whole length of the iliac crest, between the origins of the Transversus and Iliacus; between the anterior superior iliac spine and the femoral vessels it is connected to the posterior margin of the inguinal ligament, and is there continuous with the iliac fascia. Medial to the femoral vessels it is thin and is fixed to the pecten pubis, behind the conjoint tendon, with which it is united; it descends in front of the

FIG. 587.—The right Rectus abdominis and the left Pyramidalis. The greater part of the left Rectus abdominis has been removed to show the superior and inferior epigastric vessels.

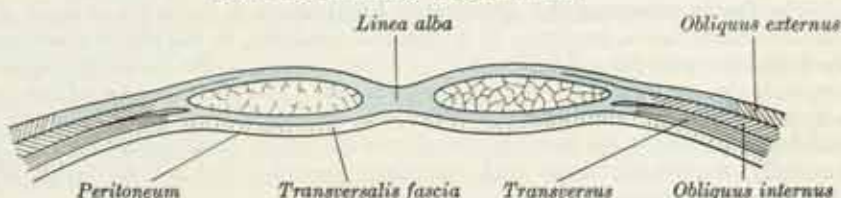


femoral vessels to form the anterior wall of the femoral sheath. In front of the femoral vessels the transversalis fascia is strengthened by transversely arched fibres which spread out laterally towards the anterior superior iliac spine and medially splay out behind the rectus abdominis muscle, while some descend to the pecten pubis behind the conjoint tendon. These arched fibres constitute the *deep crural arch* (fig. 586). The spermatic cord in the male, and the round ligament of the uterus in the female, pass through the transversalis fascia at a spot called the *deep*

inguinal ring. This opening is not visible externally since the transversalis fascia is prolonged on these structures as the *internal spermatic fascia*. The arched fibres of the deep crural arch thicken the medial and inferior boundary of the deep inguinal ring (fig. 586).

The **deep inguinal ring** is situated in the transversalis fascia, midway between the anterior superior iliac spine and the symphysis pubis, and 1.25 cm. above the inguinal ligament. It is of an oval form, the long axis of the oval being vertical; it varies in size in different subjects, and is much larger in the male than in the female. It is related above to the arched lower margin of the Transversus

FIG. 588.—A transverse section through the anterior abdominal wall immediately above the umbilicus. Diagrammatic.



abdominis, and medially to the inferior epigastric vessels and the interfoveolar ligament, when that structure is present. It transmits the spermatic cord in the male and the round ligament of the uterus in the female. From its circumference a thin funnel-shaped membrane, named the *internal spermatic fascia*, is continued as a covering on the spermatic cord and testis.

The **inguinal canal** contains the spermatic cord and the ilio-inguinal nerve in the male, and the round ligament of the uterus and the ilio-inguinal nerve in the female. It is an oblique canal about 4 cm. long, slanting downwards and medially, and placed parallel with, and a little above, the inguinal ligament; it extends from the deep inguinal ring to the superficial inguinal ring. It is bounded *in front* throughout its whole length by the skin, the superficial fascia, and the aponeurosis of the

FIG. 589.—A transverse section through the muscles of the anterior abdominal wall below the arcuate line. Diagrammatic.



External oblique, and in its lateral one-third by the fleshy fibres of origin of the Internal oblique muscle; *behind*, by the reflected part of the inguinal ligament, the conjoint tendon, and the transversalis fascia, which separate it from the extra-peritoneal connective tissue and the peritoneum; *above*, by the arched fibres of the Internal oblique and Transversus abdominis muscles; *below*, by the union of the transversalis fascia with the inguinal ligament, and at its medial end by the lacunar ligament.

The presence of the canal weakens the lower part of the anterior abdominal wall, but the weakness thus produced is compensated for, partly by the obliquity of the canal and partly by the arrangement of the constituent parts of its walls. Owing to the oblique direction of the canal the two inguinal rings do not lie opposite to one another, and increases in the intra-abdominal pressure exercise their effect not only at the deep inguinal ring but also on the posterior wall of the canal so as to approximate it to the anterior wall. The posterior wall of the canal is strengthened by the conjoint tendon and the reflected part of the inguinal ligament precisely opposite to the superficial inguinal ring, and the fleshy fibres of the Internal oblique muscle take part in the formation of the anterior wall, where it lies opposite to the deep inguinal ring.

The extraperitoneal tissue.—Between the peritoneum and the inner surface of the general layer of the fascia which lines the interior of the abdominal and pelvic cavities, there is a considerable amount of fibro-areolar tissue, termed the *extra-*

peritoneal tissue. It varies in quantity in different situations. It is especially abundant on the posterior wall of the abdomen, and particularly around the kidneys, where it contains much fat. It is scanty on the anterolateral wall of the abdomen, except in the pubic region and above the iliac crest; there is a considerable amount in the pelvis.

2. THE POSTERIOR MUSCLES OF THE ABDOMEN

Psoas major.

Psoas minor.

Iliacus.

Quadratus lumborum.

The Psoas major, the Psoas minor, and the Iliacus, with the fasciæ covering them, are described with the muscles of the lower limb (pp. 652 to 654).

The **fascia covering the Quadratus lumborum** is the anterior layer of the thoracolumbar fascia (p. 575). It is attached, medially, to the anterior surfaces of the transverse processes of the lumbar vertebræ; below, to the iliolumbar ligament; above, to the apex and lower border of the last rib. The upper margin of this fascia, which extends from the transverse process of the first lumbar vertebra to the apex and lower border of the last rib, constitutes the lateral lumbocostal arch (p. 585). Laterally, the fascia blends with the fused posterior and middle layers of the thoracolumbar fascia (fig. 571).

The **Quadratus lumborum** (figs. 572, 577) is irregularly quadrilateral in shape, and broader below than above. It arises by aponeurotic fibres from the iliolumbar ligament and the adjacent portion of the iliac crest for about 5 cm., and is inserted into the medial one-half of the lower border of the last rib, and by four small tendons into the apices of the transverse processes of the upper four lumbar vertebræ. Occasionally a second portion of this muscle is found in front of the preceding; it arises from the upper borders of the transverse processes of the lower three or four lumbar vertebræ, and is inserted into the lower margin and the lower part of the anterior surface of the last rib.

In front of the Quadratus lumborum are the colon, the kidney, the Psoas major et minor, and the Diaphragm; the subcostal, iliohypogastric, and ilio-inguinal nerves lie in front of the fascia which covers the muscle but are bound down to it by the continuation medially of the transversalis fascia.

Nerve-supply.—The Quadratus lumborum is supplied by the ventral rami of the twelfth thoracic and upper three or four lumbar nerves.

Actions.—The Quadratus lumborum fixes the last rib, and acts as a muscle of inspiration by helping to steady the origin of the Diaphragm. If the pelvis is fixed, it may act upon the vertebral column, flexing it to the same side; and when both muscles act together they help to extend the lumbar part of the vertebral column.

V. THE MUSCLES OF THE PELVIS

Obturator internus.

Piriformis.

Levator ani.

Coccygeus.

The muscles within the pelvis may be divided into two groups: (1) the Piriformis and the Obturator internus, which are described with the muscles of the lower limb (pp. 665, 668); (2) the Levator ani and the Coccygeus, which, with the corresponding muscles of the opposite side, form the *pelvic diaphragm*. The classification of the two groups under a common heading is convenient in connexion with the fasciæ investing the muscles. These fasciæ are closely related to one another and to the deep fascia of the perineum, and in addition are connected with the fascial coverings of the pelvic viscera; it is customary therefore to describe them together under the term *pelvic fascia*.

Pelvic fascia.—The fascia of the pelvis may be resolved into: (A) the fascial sheaths of the pelvic muscles, the *parietal pelvic fascia*; (B) the fascial sheaths of the pelvic viscera, the *visceral pelvic fascia* (see section on Splanchnology).

The parietal pelvic fascia covering the pelvic surface of the Obturator internus is well differentiated and is termed the *obturator fascia*. Above, it is connected to the posterior part of the arcuate line of the hip bone, and is there continuous with the iliac fascia. In front of this, as it follows the line of origin of the obturator internus, it gradually separates from the iliac fascia, and the continuity between the two is retained only through the periosteum. It arches below the obturator vessels and

nerve, completing the obturator canal, and at the front of the pelvis is attached to the back of the body of the pubis. Above the tendinous arch of the pelvic fascia (below) the obturator fascia is tough and aponeurotic; below that level, where it forms the lateral wall of the ischio-rectal fossa, it is thin and membranous. In the latter situation it is intimately related to the fascial sheath of the internal pudendal vessels. Behind, it is indirectly continuous with the fascia of the Piriformis.

The internal pudendal vessels and their accompanying nerves are placed in the lateral wall of the ischio-rectal fossa, and are enclosed in a special sheath of fascia named the *pudendal canal*. This sheath covers the lower part of the obturator fascia, extending upwards to blend with the inferior fascia of the pelvic diaphragm and downwards to become continuous with the falciform process of the sacrotuberous ligament (p. 507). It is sometimes termed the *lunate fascia*. In front it passes deep to the perineal membrane, blending with its lateral margin at its attachment to the inner surface of the inferior ramus of the pubis.

The *fascia of the Piriformis* is very thin and is attached to the front of the sacrum around the margins of the anterior sacral foramina. At its sacral attachment it comes into intimate association with and ensheathes the nerves emerging from these foramina; hence the sacral nerves are frequently described as lying behind the fascia. The internal iliac vessels and their branches, on the other hand, lie in the extra-peritoneal tissue in front of the fascia, and the branches of these vessels to the gluteal region emerge in special sheaths of this tissue, above and below the Piriformis muscle.

The *fascia of the pelvic diaphragm* covers both surfaces of the Levatores ani. That on the lower surface of the muscle is very thin, and is known as the *inferior fascia of the pelvic diaphragm (anal fascia)*; it forms the medial wall of the ischio-rectal fossa, and above is continuous with the fascia of the pudendal canal and the obturator fascia along the line of origin of the Levator ani; it is continuous below with the fascia on the Sphincter urethræ and the Sphincter ani externus. The fascia covering the upper surface of the Levator ani is the *superior fascia of the pelvic diaphragm*. On its lateral side it follows the line of origin of the muscle, and is therefore somewhat variable. In front it is attached to the back of the symphysis pubis about 2 cm. above its lower border, and can be traced laterally across the back of the superior ramus of the pubis for a distance of 1.25 cm., when it reaches the obturator fascia. It blends with this fascia along a line which pursues a somewhat irregular course to the spine of the ischium. The irregularity of this line is explained by the fact that whereas in lower mammals the Levator ani arises posteriorly from the pelvic brim, in man it has descended to a lower level, leaving its aponeurosis of origin as the tough upper part of the obturator fascia. In some cases tendinous fibres of origin extend up towards, and may reach, the pelvic brim. Internally the superior fascia of the pelvic diaphragm blends with the visceral pelvic fascia. The fascia covering that part of the Obturator internus which lies above the origin of the Levator ani is therefore a composite structure and includes, (a) the obturator fascia, (b) the fascia of the Levator ani, and (c) the degenerated fibres of origin of the Levator ani.

At the level of a line extending from the lower part of the symphysis pubis to the spine of the ischium there is a thickened whitish band in the superior fascia of the pelvic diaphragm. It is termed the *tendinous arch* of the pelvic fascia, and marks the line of attachment of the lateral true ligament of the urinary bladder. Anteriorly the fascia forms two thickened bands, named the *puboprostatic ligaments*, one on each side of the median plane.

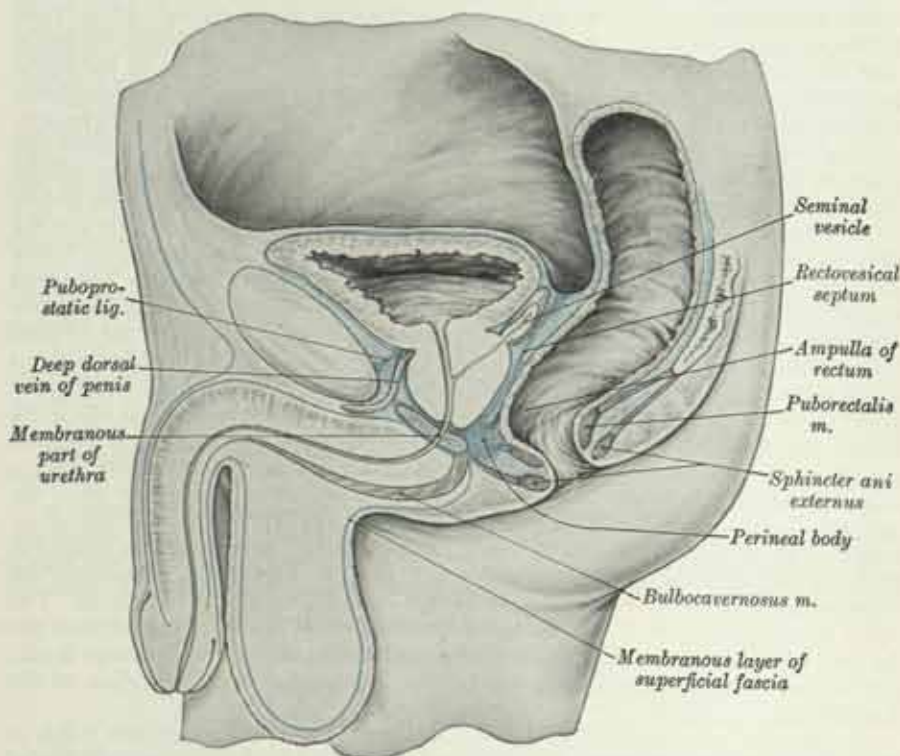
The **Levator ani** (fig. 591) is a broad, thin muscle; it is attached to the inner surface of the side of the true pelvis, and unites with its fellow of the opposite side to form the greater part of the floor of the pelvic cavity. It arises, in front, from the pelvic surface of the body of the pubis lateral to the symphysis; behind, from the inner surface of the spine of the ischium; and between these two points, from the obturator fascia. Posteriorly this origin from the obturator fascia corresponds, more or less closely, with the tendinous arch of the pelvic fascia, but in front, the muscle arises from the fascia at a varying distance above the arch, in some cases reaching nearly as high as the canal for the obturator vessels and nerve. The fibres pass towards the median plane with varying degrees of obliquity. (a) The most anterior fibres sweep backwards and downwards across the side of the prostate to be inserted into the perineal body (p. 608). They constitute the *Levator prostatae* in the male, but in the female they cross the sides of the vagina to reach their insertion, and so

constitute an additional and important sphincter for that structure. (b) The succeeding fibres pass backwards and downwards across the side of the prostate and then turn medially at the anorectal flexure to become continuous with the corresponding fibres of the opposite side, but a number of them blend with the longitudinal coat of the rectum and descend as a longitudinal coat for the anal canal, deep to the external but superficial to the internal sphincter (p. 606). This part of the muscle is termed the *Puborectalis*. (c) The remaining fibres are inserted into the side of the last two segments of the coccyx and into a median fibrous raphe which stretches between the coccyx and the anorectal flexure.

Morphologically, the Levator ani may be divided into Iliococcygeus and Pubococcygeus.

The *Iliococcygeus* arises from the ischial spine and from the posterior part of the tendinous arch of the pelvic fascia, and is attached to the coccyx and the median raphe;

FIG. 590.—A median sagittal section through the pelvis, showing the arrangement of the fasciae. Diagrammatic.



it is usually thin, and may fail entirely or be replaced largely by fibrous tissue. An accessory slip at its posterior part is sometimes named the *Iliosacralis*. The *Pubococcygeus* arises from the back of the pubis and from the anterior part of the obturator fascia, and is directed backwards almost horizontally along the side of the anal canal. Between the coccyx and the anal canal the *Pubococcygei* come together and form a thick, fibromuscular layer lying on the raphe formed by the *Iliococcygei*. In lower mammals both muscles are inserted only into the caudal vertebrae. The *Iliococcygeus* is responsible for side to side movements of the tail, and the *Pubococcygeus* draws it downwards and forwards between the hind limbs. The gradual disappearance of the tail sets free these muscles to meet the demands for a more complete pelvic floor made by the gradual adoption of the erect attitude.

The Levator and Depressor caudæ muscles are represented by the rudimentary Ventral and Dorsal sacrococcygeal muscles (*Flexor* and *Extensor coccygis*). These consist of delicate muscle slips which run from the sacrum to the coccyx over the dorsal and ventral aspects of the sacrococcygeal joint.

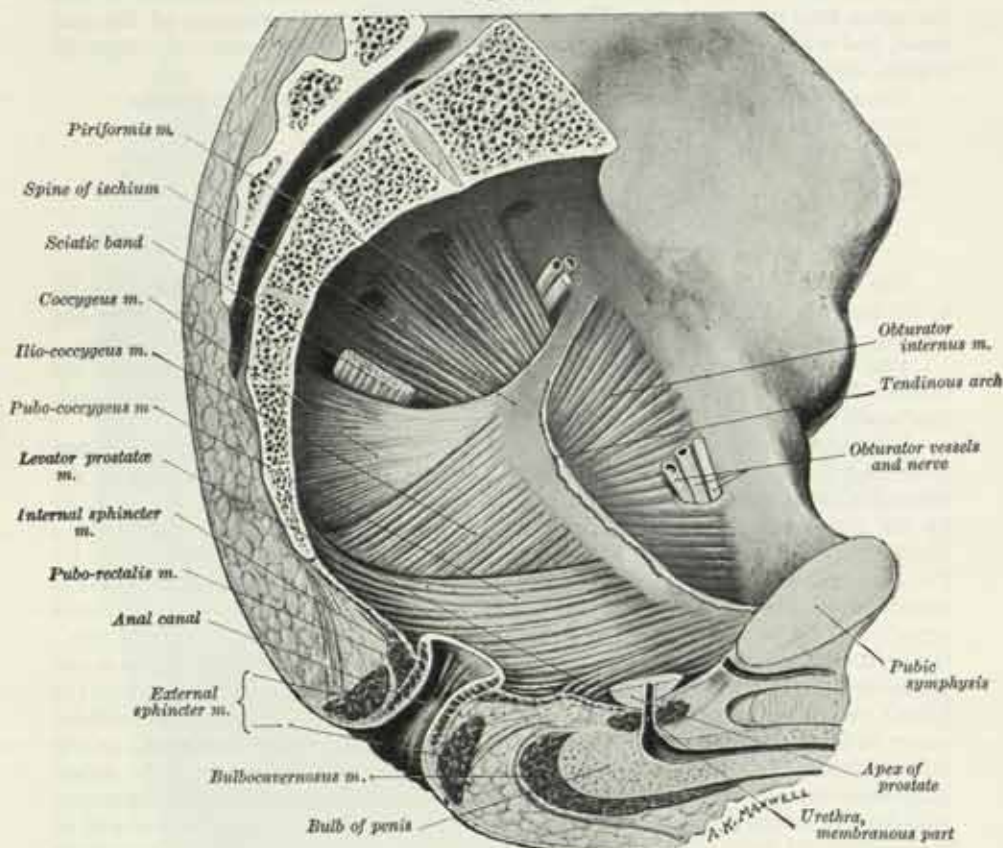
Relations.—The upper or pelvic surface of the Levator ani is separated by its covering fascia from the bladder, prostate, rectum, and peritoneum. Its lower or perineal surface forms the medial boundary of the ishiorectal fossa, and is covered by

the inferior fascia of the pelvic diaphragm. Its *posterior border* is free and separated from the Coccygeus muscle by areolar tissue. Its *anterior border* is separated from the muscle of the opposite side by a triangular space, through which the urethra and, in the female, the vagina pass from the pelvis.

Nerve-supply.—The Levator ani is supplied by a branch from the fourth sacral nerve and by a branch which arises either from the inferior rectal nerve (p. 1190) or from the perineal division of the pudendal nerve.

Actions.—The Levatores ani constrict the lower end of the rectum and vagina and steady the perineal body. Together with the Coccygei they form a muscular

FIG. 591.—The left Levator ani and Coccygeus muscles, viewed from the pelvic aspect.



The superior gluteal vessels and nerve have been cut close to the upper border of the Piriformis muscle; the anal canal has been divided below the anorectal flexure; and the greater part of the prostate has been removed. The constituent parts of the Levator ani muscle described in the text can be recognised without difficulty.

diaphragm which supports the pelvic viscera and opposes itself to the downward thrust produced by any increase in the intra-abdominal pressure.

The **Coccygeus** (fig. 591) is situated behind the Levator ani. It is a triangular sheet of muscular and tendinous fibres, arising by its apex from the pelvic surface of the spine of the ischium and from the sacrospinous ligament, and inserted by its base into the margin of the coccyx and into the side of the lowest piece of the sacrum. It assists the Levator ani and Piriformis in closing the posterior part of the outlet of the pelvis.

Nerve-supply.—The Coccygeus is supplied by a branch from the fourth and fifth sacral nerves.

Actions.—The Coccygei pull forward and support the coccyx, after it has been pressed backwards during defæcation or parturition.

Applied Anatomy.—Injury to the muscles forming the pelvic floor occurs not infrequently during parturition. When the perineal body (p. 608) has been torn through,

and has not been repaired satisfactorily, the contraction of the anterior fibres of the Levator ani increases instead of diminishing the normal gap in the pelvic floor, and a cystocele results. In severe cases the uterus, ovaries and rectum may also prolapse.

VI. THE MUSCLES OF THE PERINEUM

The perineum overlies the outlet of the pelvis. Its deep boundaries are—in front, the pubic arch and the arcuate pubic ligament; behind, the tip of the coccyx; and on each side the inferior ramus of the pubis and the ramus of the ischium, the ischial tuberosity and the sacrotuberous ligament. The space within these boundaries is somewhat lozenge-shaped. On the surface of the body the perineum is limited by the scrotum in front, the buttocks behind, and the medial sides of the thighs laterally. A line drawn transversely in front of the ischial tuberosities divides the space into two portions. The posterior contains the termination of the anal canal, and is known as the *anal region*; the anterior contains the external urogenital organs, and is termed the *urogenital region*.

The muscles of the perineum may therefore be divided into two groups:

1. Those of the anal region.
2. Those of the urogenital region: A, In the male; B, In the female.

1. THE MUSCLES OF THE ANAL REGION

Sphincter ani externus.

The **superficial fascia** is very thick, areolar in texture, and contains much fat in its meshes. On each side a pad of fatty tissue extends deeply between the Levator ani and Obturator internus into a space known as the *ischiorectal fossa*.

The **deep fascia** forms the lining of the ischiorectal fossa; it comprises the inferior fascia of the pelvic diaphragm, and that part of the obturator fascia which lies below the origin of Levator ani.

Ischiorectal fossa.—The fossa is somewhat wedge-shaped, with its base directed to the surface of the perineum, and its thin edge at the line of meeting of the obturator fascia and inferior fascia of the pelvic diaphragm. It is bounded medially by the Sphincter ani externus and the inferior fascia of the pelvic diaphragm; laterally, by the tuberosity of the ischium and the obturator fascia; anteriorly, by the inferior fascia of the urogenital diaphragm (p. 608); posteriorly, by the Gluteus maximus muscle (lower border) and the sacrotuberous ligament. The inferior rectal vessels and nerve cross the space transversely from the lateral to the medial side; the perineal and perforating cutaneous branches of the sacral plexus are found in the posterior part of the fossa; while from the anterior part the posterior scrotal (or labial) vessels and nerves emerge. The internal pudendal vessels and pudendal nerve lie on the lateral wall of the fossa, in the pudendal canal (p. 603) and, as the fascial sheath of the vessels extends upwards to the inferior fascia of the pelvic diaphragm and downwards to the falciform process of the sacrotuberous ligament, with both of which it blends, it is sometimes regarded as forming the lateral wall of the ischiorectal fossa. The fossa is filled with fatty tissue, across which numerous fibrous bands extend.

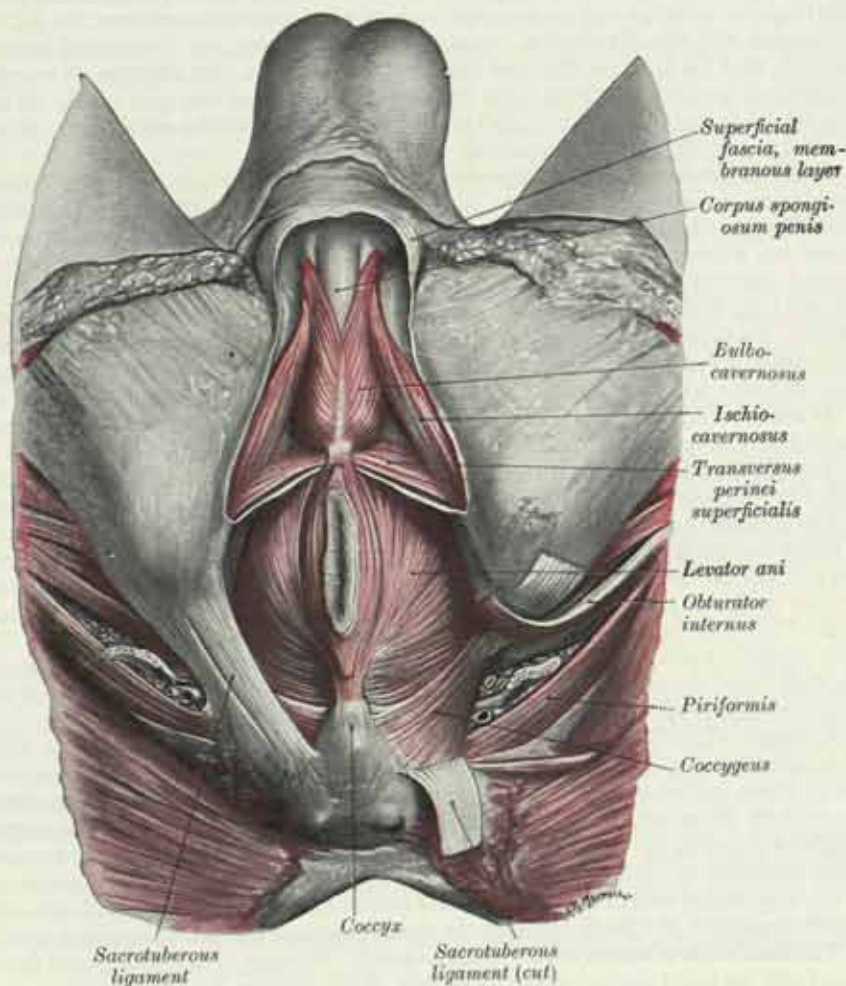
The **Sphincter ani externus** (figs. 1201, 1202) is a sheet of muscular fibres, elliptical in shape and intimately adherent to the skin surrounding the anus. It consists of three portions, subcutaneous, superficial and deep. The *subcutaneous portion* is a flat band, about 15 mm. broad, which surrounds the lowermost part of the anal canal up to the 'white line' (p. 1443). The *superficial portion* arises by a narrow tendinous band from the dorsal aspect of the tip of the coccyx; the muscle consists of two flattened sheets which pass one on each side of the anal canal, deep to the subcutaneous portion, and meet in front to be inserted into the perineal body, joining with the Transversus perinei superficialis, the Levator ani, and the Bulbo-cavernosus muscles. The *deep portion* forms a complete sphincter to the upper end of the anal canal. Its fibres surround the canal, closely applied to the Puborectalis and the Sphincter ani internus, and in front blend with the other muscles at the perineal body (fig. 590). The upper edge of the muscle is ill-defined, since it receives numerous fibres from the Puborectalis (see also p. 1444).*

* E. T. C. Milligan and C. N. Morgan, *Lancet*, 1934, p. 1151, and 1937, p. 1119. J. C. Goligher, A. G. Leacock and J.-J. Brossy, *Brit. J. Surg.*, 43, 1955, have failed to find a clear division of the External sphincter into these three parts.

Nerve-supply.—The Sphincter ani externus is supplied by the perineal branch of the fourth sacral nerve and by twigs from the inferior rectal branch (S. 2 and 3) of the pudendal nerve.

Actions.—The Sphincter ani externus is normally in a state of tonic contraction, and having no antagonistic muscle it keeps the anal canal and orifice closed. It can be put into a condition of greater contraction under the influence of the will, so as to occlude the anal aperture more firmly. Taking its fixed point at the coccyx, it helps to fix the perineal body.

FIG. 592.—The muscles of the male perineum. (From Quain's *Anatomy*, XI. Edition.)



2. A. THE MUSCLES OF THE UROGENITAL REGION IN THE MALE (fig. 592)

Transversus perinei superficialis.

Bulbocavernosus.

Ischiocavernosus.

Transversus perinei profundus.

Sphincter urethræ.

The **superficial fascia** of this region consists of a superficial, fatty, and a deeper, membranous layer.

The **fatty layer** is thick, loose, areolar in texture, and contains a variable amount of fat in its meshes. In front, it is continuous with the dartos muscle of the scrotum; behind, with the subcutaneous areolar tissue surrounding the anus; and, on each side, with the same fascia on the medial sides of the thighs. In the median plane, it is adherent to the skin and to the membranous layer of the superficial fascia.

The **membranous layer of superficial fascia** (fig. 590) is thin, aponeurotic in struc-

ture, and of considerable strength, serving to bind down the muscles of the root of the penis. It is continuous, in front, with the dartos muscle, the fascia penis, and the membranous layer of the superficial fascia upon the anterior wall of the abdomen; on each side it is attached to the margins of the rami of the pubis and ischium, lateral to the crus penis and as far back as the tuberosity of the ischium; posteriorly it curves round the *Transversi perinei superficiales* to join the posterior margins of the fasciæ of the urogenital diaphragm and the perineal body. Between the membranous layer of superficial fascia and the inferior fascia of the urogenital diaphragm is the *superficial perineal space*.

The perineal body.—This is a fibromuscular node in the median plane, about 1.25 cm. in front of the anus, and close to the bulb of the penis. Towards this point eight muscles converge and are attached: viz. the *Sphincter ani externus*, the *Bulbocavernosus*, the two *Transversi perinei superficiales*, the two *Transversi perinei profundi*, and the anterior fibres of the two *Levatores ani*. In addition, it receives longitudinal involuntary fibres from the rectal ampulla and the anal canal. It is a compact little node, and the importance of its integrity to the pelvic floor in the female has already been mentioned (p. 605).

The *Transversus perinei superficialis* is a narrow muscular slip which passes more or less transversely across the perineal space in front of the anus. It is often feebly developed, and is sometimes absent. It arises by tendinous fibres from the medial and anterior part of the tuberosity of the ischium, and, running medially, is inserted into the perineal body, joining in this situation with the muscle of the opposite side, with the *Sphincter ani externus* behind, and with the *Bulbocavernosus* in front. In some cases, the fibres of the deeper layer of the *Sphincter ani externus* decussate in front of the anus and are continued into this muscle. Occasionally it gives off fibres which join with the *Bulbocavernosus* of the same side.

Action.—The simultaneous contraction of the two *Transversi perinei superficiales* helps to fix the perineal body.

The *Bulbocavernosus* (*Bulbospongiosus*) is placed in the median line of the perineum, in front of the anus, and consists of two symmetrical parts, united by a median tendinous raphe. It arises from this median raphe and from the perineal body. Its fibres diverge like the barbs of a quill-pen; the most posterior form a thin layer, which is lost on the inferior fascia of the urogenital diaphragm; the middle fibres encircle the bulb and the adjacent part of the corpus spongiosum penis, and are inserted into a strong aponeurosis on the upper part of that structure; the anterior fibres spread out over the side of the corpus cavernosum penis, to be inserted partly into that body, anterior to the *Ischiocavernosus*, and partly into a tendinous expansion which covers the dorsal vessels of the penis.

Actions.—The *Bulbocavernosus* serves to empty the canal of the urethra, after the bladder has expelled its contents; during the greater part of the act of micturition its fibres are relaxed, and they only come into action at the end of the process. The middle fibres are supposed by Krause to assist in the erection of the corpus spongiosum penis, by compressing the erectile tissue of the bulb. The anterior fibres, according to Tyrrel, also contribute to the erection of the penis by compressing the deep dorsal vein of the penis, as their tendinous expansion is inserted into, and is continuous with, the fascia covering the dorsal vessels of the penis (*see also* p. 1504).

The *Ischiocavernosus* covers the crus penis. It arises by tendinous and fleshy fibres from the inner surface of the tuberosity of the ischium, behind the crus penis; and from the ramus of the ischium on both sides of the crus. The muscular fibres end in an aponeurosis which is inserted into the sides and under surface of the crus penis.

Action.—The *Ischiocavernosus* compresses the crus penis, and so may play a part in maintaining erection of the penis.

Between the muscles just examined a triangular space exists, bounded medially by the *Bulbocavernosus*, laterally by the *Ischiocavernosus*, and behind by the *Transversus perinei superficialis*; the floor is formed by the inferior fascia of the urogenital diaphragm. The posterior scrotal vessels and nerves, and the perineal branch of the posterior femoral cutaneous nerve traverse the space from behind forwards; the transverse perineal artery courses along its posterior boundary on the *Transversus perinei superficialis*.

The muscles of the urogenital region together with the fasciæ investing them constitute the *urogenital diaphragm*. Superficial to the *Transversus perinei profundus* and the *Sphincter urethræ* is the *inferior fascia of the urogenital diaphragm*.

(*perineal membrane*). This forms a strong layer stretching almost horizontally across the pubic arch. Its base, directed backwards, is connected to the perineal body and is continuous with the inferior fascia of the pelvic diaphragm and, behind the *Transversus perinei superficialis*, with the membranous layer of the superficial fascia. Its lateral margins are attached to the inferior ramus of the pubis and the ramus of the ischium, above the crus penis. Its apex, directed forwards, is thickened to form the *transverse perineal ligament*; between this ligament and the arcuate pubic ligament the deep dorsal vein of the penis (or clitoris) enters the pelvis and the dorsal nerve of the penis passes forwards to gain the dorsum of the penis. It is perforated, from 2 to 3 cm. behind the lower edge of the symphysis pubis, by the urethra, the aperture for which is circular and about 6 mm. in diameter; by the arteries and nerves to the bulb and, close to the urethra, by the ducts of the bulbo-urethral glands; by the deep arteries of the penis, one on each side close to the pubic arch and about halfway along its attached margin; by the dorsal arteries of the penis near its apex. Its base is also perforated by the posterior scrotal vessels and nerves.

Deep to the *Transversus perinei profundus* muscle and the *Sphincter urethræ* is a less definite layer of fascia, the *superior fascia of the urogenital diaphragm*. It stretches across the pubic arch and is continuous laterally with the obturator fascia. Behind it blends with the inferior fascia of the urogenital diaphragm, the perineal body and the membranous layer of the superficial fascia; above, it is pierced by the urethra and is continuous at this point with the prostatic fascia.

Between the superior and inferior fasciæ of the urogenital diaphragm is the deep perineal space. In it lie the membranous portion of the urethra, the *Transversus perinei profundus* and the *Sphincter urethræ*, the bulbo-urethral glands and their ducts, the pudendal vessels and dorsal nerves of the penis in the forward continuation of the pudendal canal, the arteries and nerves of the bulb of the penis, and a plexus of veins.

The *Transversus perinei profundus* arises from the fascial sheath of the pudendal vessels over the ramus of the ischium and runs to the median plane, where it interlaces in a tendinous raphe with its fellow of the opposite side and gains attachment to the perineal body. It lies in the same plane as the *Sphincter urethræ*; formerly the two muscles were described together as the *Constrictor* or *Compressor urethræ*.

Action.—The *Transversus perinei profundus* helps to steady the perineal body.

The *Sphincter urethræ* surrounds the membranous portion of the urethra, and lies deep to the inferior fascia of the urogenital diaphragm. Its *superficial* or *inferior* fibres arise in front from the transverse perineal ligament and from the neighbouring fasciæ. They pass backwards on each side of the urethra and converge on the perineal body for their insertion. Its *deep* fibres, some of which arise from the fascial sheath of the pudendal vessels and pass medially (fig. 773), form a continuous circular investment for the membranous urethra.

Actions.—The muscles of both sides act together as a sphincter, compressing the membranous portion of the urethra. During micturition they, like the *Bulbocavernosus*, are relaxed, and only come into action at the end of the process to eject the last drops of urine.

Nerve-supply.—All the muscles of the urogenital region are supplied by the perineal branch of the pudendal nerve (S. 2, 3 and 4).

2. B. THE MUSCLES OF THE UROGENITAL REGION IN THE FEMALE (fig. 593)

Transversus perinei superficialis.

Ischiocavernosus.

Bulbospongiosus.

Transversus perinei profundus.

Sphincter urethræ.

The *Transversus perinei superficialis* in the female is a narrow muscular slip, which differs but little from the corresponding muscle in the male (p. 608).

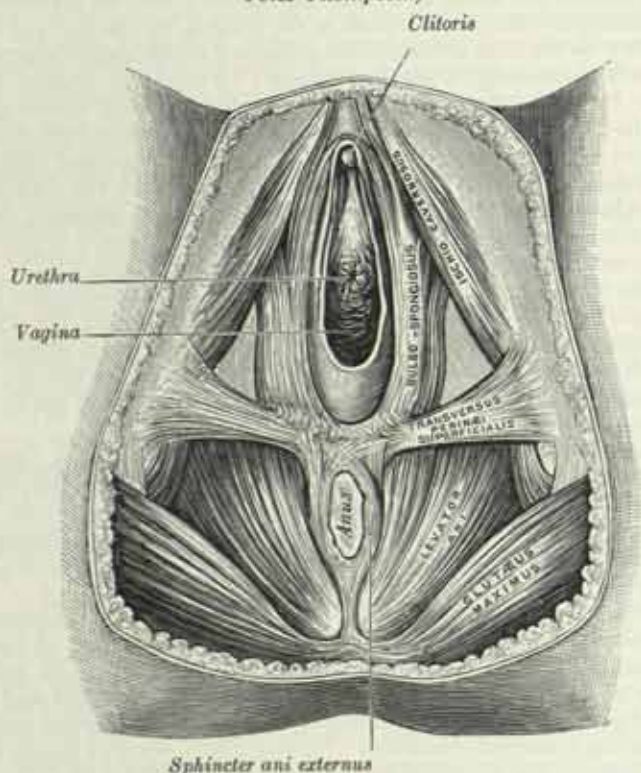
The *Bulbocavernosus* surrounds the orifice of the vagina. It covers the lateral parts of the vestibular bulbs, and is attached posteriorly to the perineal body, where it blends with the *Sphincter ani externus*. Its fibres pass forwards on each side of the vagina, to be inserted into the corpora cavernosa clitoridis; a fasciculus crosses over the body of the clitoris so as to compress the deep dorsal vein.

Actions.—The *Bulbocavernosus* diminishes the orifice of the vagina. The

anterior fibres contribute to the erection of the clitoris by the compression of its deep dorsal vein.

The **Ischiocavernosus**, smaller than the corresponding muscle in the male, covers the unattached surface of the crus clitoridis. It arises by tendinous and fleshy fibres from the inner surface of the tuberosity of the ischium, behind the crus clitoridis; and from the adjacent portion of the ramus of the ischium. The muscular fibres end in an aponeurosis which is inserted into the sides and under surface of the crus clitoridis.

FIG. 593.—The muscles of the female perineum. (Modified from a drawing by Peter Thompson.)



Actions.—The Ischiocavernosus compresses the crus clitoridis and retards the return of blood through the veins, thus serving to maintain the clitoris erect.

The *inferior fascia of the urogenital diaphragm* in the female is weaker than that in the male, and is pierced by the aperture of the vagina, with the external coat of which it blends, as well as by the urethra and vessels and nerves corresponding to those already enumerated for the male (p. 609). It covers the following structures: portions of the urethra and the vagina, the Transversus perinei profundus and Sphincter urethræ muscles, the internal pudendal vessels, the dorsal nerves of the clitoris, the arteries and nerves of the vestibular bulbs, and a plexus of veins.

The **Transversus perinei profundus** arises from the fascial sheath of the pudendal canal over the ramus of the ischium and runs across behind the vagina to meet the corresponding muscle of the opposite side. The more anterior fibres become lost in the vaginal wall.

Action.—The Transversus perinei profundus helps to steady the perineal body.

The **Sphincter urethræ**, like the corresponding muscle in the male, consists of external and internal fibres. The *external* fibres arise on either side from the transverse perineal ligament and sweep backwards on each side of the urethra. Some of the fibres interlace with those of the opposite side between the urethra and the vagina, while others can be traced to the vaginal wall. The *innermost* fibres encircle the lower end of the urethra.

Actions.—The muscles of the two sides act as a constrictor of the urethra.

THE FASCIÆ AND MUSCLES OF THE UPPER LIMB

The muscles of the upper limb are divisible into the following groups :

- | | |
|---|-------------------------------|
| I. Muscles connecting the upper limb with the vertebral column. | |
| II. Muscles connecting the upper limb with the anterior and lateral thoracic walls. | |
| III. Muscles of the shoulder. | IV. Muscles of the upper arm. |
| V. Muscles of the forearm. | VI. Muscles of the hand. |

I. THE MUSCLES CONNECTING THE UPPER LIMB WITH THE VERTEBRAL COLUMN

Trapezius.

Latissimus dorsi.

Rhomboides major.

Rhomboides minor.

Levator scapulæ.

The **superficial fascia** of the back forms a layer of considerable thickness and strength, and contains a quantity of granular fat. It is continuous with the general superficial fascia. In the upper part of the neck it forms a thick, tough layer, characterised by the presence of numerous white connective tissue fibres by means of which it is firmly connected to the overlying skin.

The **deep fascia** of the back is a dense fibrous layer where it is attached above to the superior nuchal line of the occipital bone ; and in the median plane where it is fixed to the ligamentum nuchæ and supraspinous ligament, and to the spines of all the vertebræ below the seventh cervical. Elsewhere it is, for the most part, a thin fibrous membrane. Laterally, in the neck it is continuous with the deep cervical fascia ; over the shoulder it is attached to the spine and acromion of the scapula, and is continued downwards over the Deltoid to the arm ; on the thorax it is continuous with the deep fascia of the axilla and chest, and on the abdomen with that covering the abdominal muscles ; below, it is attached to the crest of the ilium.

The **Trapezius** (fig. 594) is a flat, triangular muscle, covering the back of the neck and shoulder. It arises from the medial one-third of the superior nuchal line of the occipital bone, the external occipital protuberance, the ligamentum nuchæ, the spine of the seventh cervical, and the spines of all the thoracic vertebræ, and the corresponding portion of the supraspinous ligament. The superior fibres proceed downwards and laterally, the inferior upwards and laterally, and the middle horizontally ; the superior fibres are inserted into the posterior border of the lateral one-third of the clavicle ; the middle fibres into the medial margin of the acromion and the superior lip of the crest of the spine of the scapula ; the inferior fibres converge and end in an aponeurosis, which glides over the smooth triangular surface at the medial end of the spine of the scapula and is inserted into a tubercle at the apex of this smooth triangular surface. The upper part of the Trapezius is connected to the occipital bone by a thin fibrous lamina, firmly adherent to the skin ; the middle part arises by a broad semi-elliptical aponeurosis, which reaches from the sixth cervical to the third thoracic vertebra ; the lower part arises by short tendinous fibres. The two Trapezius muscles together resemble a trapezium, or quadrangle ; the lateral angles corresponding to the shoulders ; the superior to the occipital protuberance ; and the inferior to the spine of the twelfth thoracic vertebra.

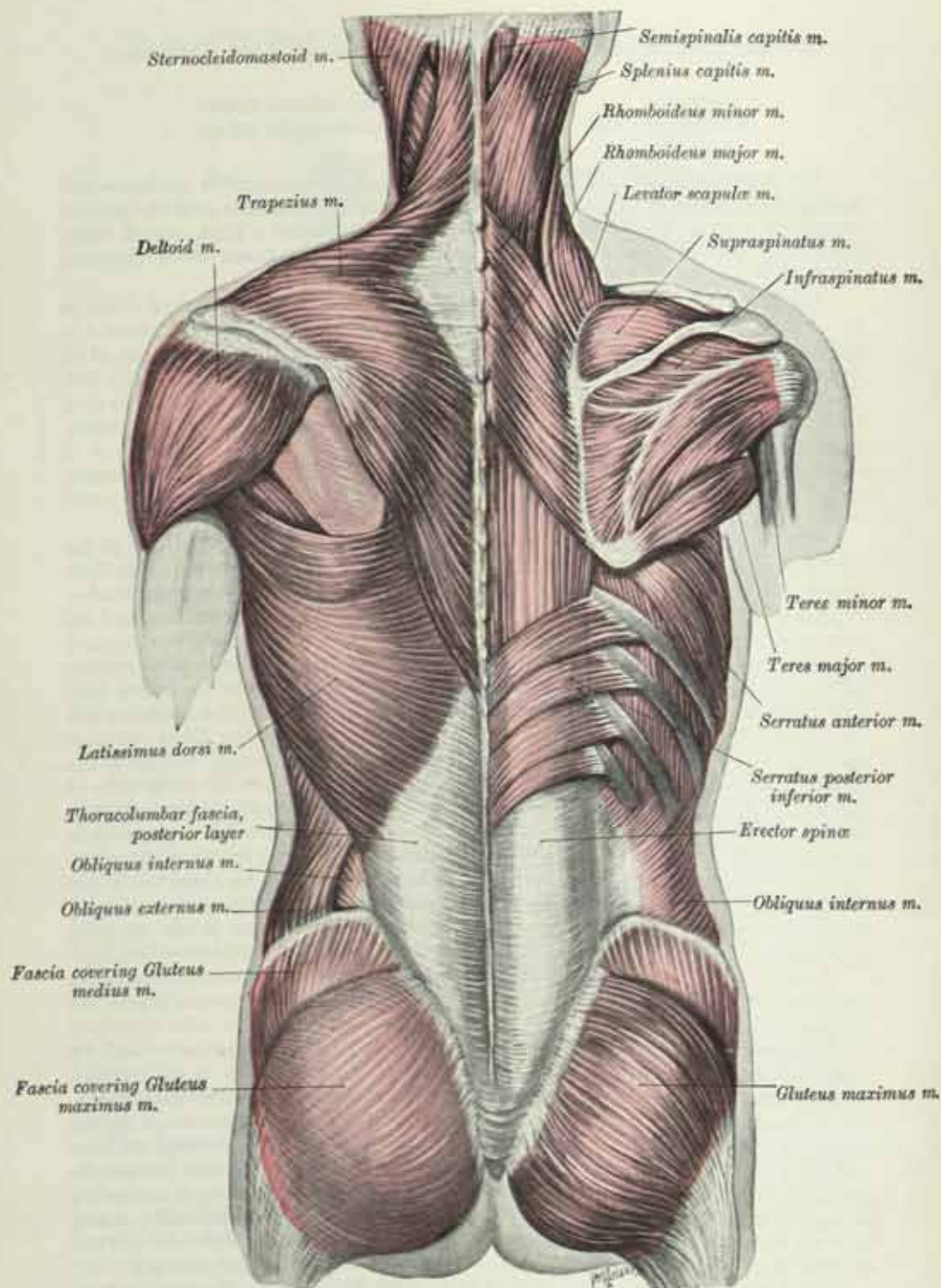
The clavicular insertion of this muscle varies in extent ; it sometimes reaches as far as the middle of the clavicle, and occasionally blends with the posterior edge of the Sternocleidomastoid.

Nerve-supply.—The Trapezius is supplied by the accessory nerve and by branches from the third and fourth cervical nerves.

Actions.—Acting in association with the other muscles inserted into the scapula, the Trapezius steadies that bone and controls its position and movements during active use of the upper limb. In this way it is responsible for maintaining the level and poise of the shoulder. Acting with the Levator scapulæ, it elevates the scapula and with it the point of the shoulder ; acting with the Serratus anterior, it rotates the scapula in a forward direction so that the arm can be raised above the head ; acting with the Rhomboids, it retracts the scapula and so braces back the shoulder. When the shoulder is fixed, the Trapezius draws the head backwards and laterally.

The **Latissimus dorsi** (fig. 594) is a large, triangular, flat muscle, which covers

FIG. 594.—A dissection to display the superficial muscles of the back of the neck and trunk. On the left side, only the skin, superficial and deep fasciae have been removed; and on the right side, the Sternocleidomastoid, Trapezius, Latissimus dorsi, Deltoid and Obliquus externus abdominis have been taken away.



the lumbar region and the lower one-half of the thoracic region; but its fibres converge to a narrow tendon of insertion. It arises by tendinous fibres from the spines of the lower six thoracic vertebræ under cover of the Trapezius, and from the posterior layer of the thoracolumbar fascia (p. 575), by which it is attached to the spines of the lumbar and sacral vertebræ, to the supraspinous ligament, and to the posterior part of the crest of the ilium. In addition, it arises by muscular fibres from the posterior part of the outer lip of the crest of the ilium, lateral to the margin of the Erector spinæ, and by fleshy slips from the three or four lower ribs; the latter interdigitate with the lower digitations of the Obliquus abdominis externus (fig. 578). From this extensive origin the fibres pass laterally with varying degrees of obliquity, the upper ones horizontally, the middle obliquely upwards, and the lower almost vertically upwards, so as to converge and form a thick fasciculus, the upper part of which crosses, and usually receives a few fibres from, the inferior angle of the scapula. The muscle is wrapped round the lower border of the Teres major, and curves round on to its anterior surface. Here it ends in a quadrilateral tendon, about 7 cm. long, which passes in front of the tendon of the Teres major, and is inserted into the bottom of the intertubercular sulcus of the humerus, giving an expansion of the deep fascia of the upper arm; its insertion extends higher on the humerus than that of the Teres major. The lower border of its tendon is united with the tendon of the Teres major, the surfaces of the two being separated near their insertions by a bursa; another bursa is sometimes interposed between the muscle and the inferior angle of the scapula. On account of the way in which the muscle curves round the lower border of the Teres major, its originally *lowest* fibres are inserted highest up on the humerus, while its originally *highest* fibres pass into the lower end of its tendon.

The Latissimus dorsi, with the underlying Teres major, forms the posterior fold of the axilla. When attempts are made to adduct the abducted arm against resistance, the posterior fold of the axilla is accentuated and the lower, or lateral, border of the muscle can be traced downwards to its attachment to the iliac crest.

A muscular slip, named the *axillary arch*, varying from 7 to 10 cm. in length, and from 5 to 15 mm. in breadth, occasionally springs from the edge of the Latissimus dorsi about the middle of the posterior fold of the axilla, and crosses the axilla in front of the axillary vessels and nerves, to join the under surface of the tendon of the Pectoralis major, the Coracobrachialis, or the fascia over the Biceps. This axillary arch crosses the axillary artery, just above the spot usually selected for the application of a ligature, and may mislead the surgeon during the operation. It is present in about seven per cent. of subjects and may be recognised easily by the direction of its fibres.

A fibrous slip usually passes from the lower border of the tendon of the Latissimus dorsi, near its insertion, to the long head of the Triceps. This is occasionally muscular, and is the representative of the *dorso-epitrochlearis brachii* of apes.

Nerve-supply.—The Latissimus dorsi is supplied by the thoracodorsal nerve from the posterior cord of the brachial plexus (C. 6, 7 and 8).*

Actions.—The Latissimus dorsi plays an active part in the movements of adduction, extension and medial rotation of the humerus. Further, it acts with the sternocostal part of the Pectoralis major and with the Teres major to depress the raised arm against resistance. When the arms are raised above the head and fixed, e.g. by gripping a horizontal bar, the same muscles act to pull the trunk upwards and forwards, a movement in which their origins are approximated to their insertions (p. 546).

In addition, the Latissimus dorsi takes part in all violent expiratory movements, such as coughing or sneezing, and when the fibres of the muscle are put on the stretch as in elevation of the arm, their tonus enables them to exert sufficient pressure on the inferior angle of the scapula to keep it in close contact with the chest wall.

The lower part of the lateral margin of the Latissimus dorsi is separated from the posterior free border of the External oblique muscle by a small triangular interval, named the *lumbar triangle*, the base of which is formed by the iliac crest, and the floor by the Internal oblique muscle (fig. 594). Another triangle, sometimes termed the *triangle of auscultation*, is situated behind the scapula. It is bounded

* Throughout the remainder of this section the use of italics for numerals indicates that it is doubtful whether the nerve italicised actually contributes to the motor innervation of the muscle. On the other hand, the use of heavy type indicates that the nerve or nerves concerned are the predominant source of motor supply.

above by the Trapezius, below by the Latissimus dorsi, and laterally by the medial border of the scapula; the floor is partly formed by the Rhomboideus major. If the scapula be drawn forwards by folding the arms across the chest, and the trunk bent forwards, parts of the sixth and seventh ribs and the interspace between them become subcutaneous in this situation and available for auscultation of the lung.

The **Rhomboideus major** (fig. 594) arises by tendinous fibres from the spines of the second, third, fourth, and fifth thoracic vertebræ and the supraspinous ligament. The fibres of the muscle are directed downwards and laterally and are inserted into the medial border of the scapula between the triangular surface of the root of the spine and the inferior angle. Usually the insertion is an indirect one, the muscular fibres ending in a tendinous band which is fixed at its ends to the two points mentioned and joined to the medial border by a thin membrane; occasionally the arch is incomplete, and some of the muscular fibres are then inserted directly into the scapula.

The **Rhomboideus minor** (fig. 594) arises from the lower part of the ligamentum nuchæ and from the spines of the seventh cervical and first thoracic vertebræ; it is inserted into the base of the triangular smooth surface at the medial end of the spine of the scapula. It is usually separated from the Rhomboideus major by a slight interval, but the edges of the two muscles are occasionally united.

Nerve-supply.—The nerve to the Rhomboids is the dorsal scapular which arises from the ventral ramus of the fifth cervical nerve in the substance of the Scalenus medius.

The **Levator scapulæ** (figs. 570, 594) is situated at the back and side of the neck. It arises by tendinous slips from the transverse processes of the atlas and axis and from the posterior tubercles of the transverse processes of the third and fourth cervical vertebræ. It is inserted into the medial border of the scapula, between the superior angle and the triangular smooth surface at the medial end of the spine.

Nerve-supply.—The Levator scapulæ is supplied directly by the third and fourth cervical nerves, and by a branch from the dorsal scapular nerve (C. 5).

Actions.—In association with the other muscles inserted into the scapula, the Rhomboids and Levator scapulæ help to steady the bone and to control its position and movements during active use of the upper limb. In this way they help to maintain the level and poise of the shoulder.

Acting with the Trapezius, the Rhomboid muscles retract the scapula and brace back the shoulder; acting with the Levator scapulæ and Pectoralis minor, they rotate the scapula so as to depress the point of the shoulder.

When the cervical part of the vertebral column is fixed, the Levator scapulæ may act with the Trapezius to elevate the scapula, or to sustain a weight carried on the shoulder. If the shoulder is fixed, the muscle inclines the neck to the same side.

II. THE MUSCLES CONNECTING THE UPPER LIMB WITH THE ANTERIOR AND LATERAL THORACIC WALLS

Pectoralis major.
Pectoralis minor.

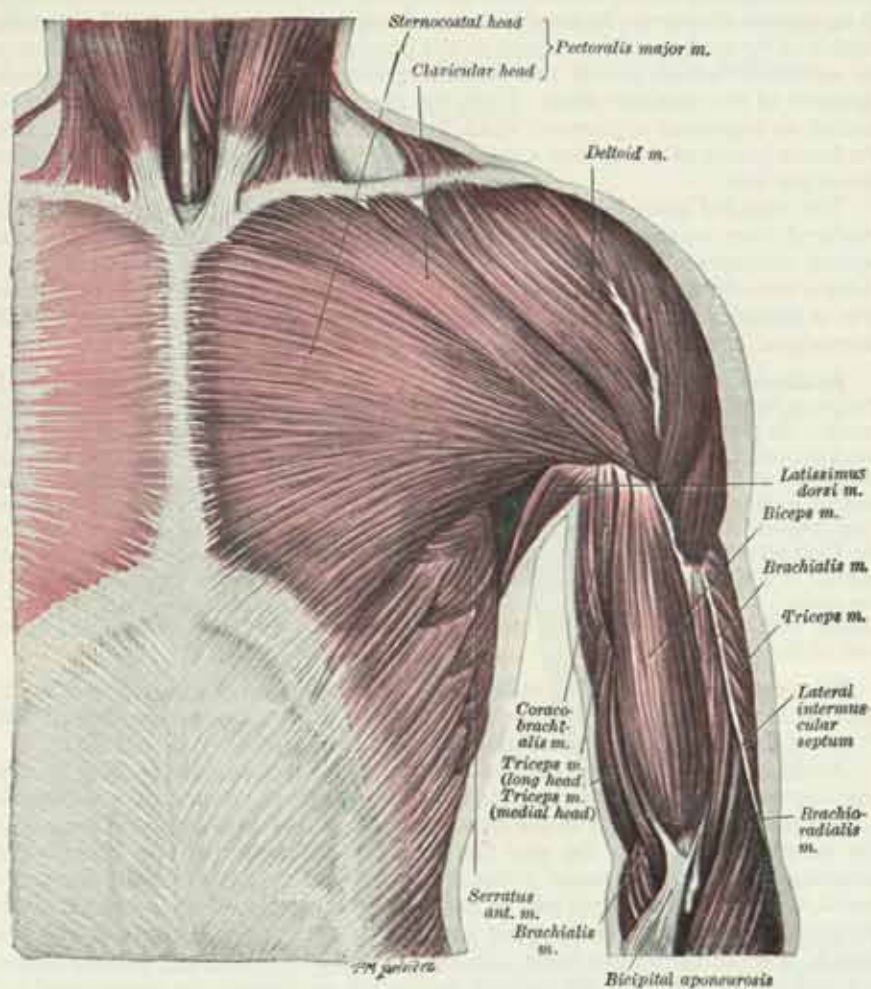
Subclavius.
Serratus anterior.

The **superficial fascia** of the anterior thoracic region is continuous with that of the neck and upper limb above, and of the abdomen below. It encloses the mammary gland and gives off numerous septa which pass into it to support its various lobes. From the fascia over the front of the gland, fibrous processes pass forwards to the integument and nipple; these were called by Sir Astley Cooper the *ligamenta suspensoria*.

The **pectoral fascia** is a thin lamina, covering the surface of the Pectoralis major and sending numerous prolongations between its fasciculi; it is attached in the median plane to the front of the sternum; above, to the clavicle; laterally and below, it is continuous with the fascia of the shoulder, axilla and thorax. It is very thin over the upper part of the Pectoralis major, but thicker in the interval between it and the Latissimus dorsi, where it forms the floor of the axillary space and is named the *axillary fascia*; this divides at the lateral margin of the Latissimus dorsi into two layers, which ensheath the muscle and are attached behind to the spines of the thoracic vertebræ. As the fascia leaves the lower edge of the Pectoralis major to

cross the floor of the axilla, it sends a layer upwards under cover of the muscle; this lamina splits to envelop the Pectoralis minor, and at the upper edge of this muscle is continuous with the clavipectoral fascia (p. 616). The hollow of the armpit, seen when the arm is abducted, is produced mainly by the traction of this fascia on the axillary floor, and hence the lamina is sometimes named the *suspensory ligament* of the axilla. At the lower part of the thoracic region the deep fascia is well developed, and is continuous with the fibrous sheath of the Rectus abdominis.

FIG. 595.—The superficial muscles of the front of the chest and upper arm. Left side.



The **Pectoralis major** (fig. 595) is a thick, triangular muscle situated at the upper and front part of the chest. It arises from the anterior surface of the sternal half of the clavicle: from half the breadth of the anterior surface of the sternum, as low down as the attachment of the cartilage of the sixth or seventh rib: from the cartilages of all the true ribs, with the exception, frequently, of the first, or seventh, or both, and from the aponeurosis of the Obliquus externus abdominis. From this extensive origin the fibres converge towards their insertion; those arising from the clavicle pass obliquely downwards and laterally, and are usually separated from the rest by a slight interval; those from the lower part of the sternum, and the cartilages of the lower true ribs, run upwards and laterally; while the middle fibres pass more or less horizontally. They all end in a flat tendon, about 5 cm. broad, which is inserted into the lateral lip of the intertubercular sulcus of the humerus. This tendon consists of two laminae, placed one in front of the other, and usually blended together below. The *anterior lamina*, the thicker, is constituted by the fibres arising

from the manubrium.* The clavicular head blends with its anterior aspect and the fibres from the margin of the sternum and from the second to the fifth costal cartilages blend with its posterior aspect. It extends as low as the tendon of the Deltoid muscle and joins with it. The *posterior lamina*, the thinner, is formed by the fibres arising from the sixth rib and costal cartilage and not infrequently by those arising from the seventh. The fibres which arise from the front of the body of the sternum and from the aponeurosis of the Obliquus abdominis externus curve round the lower border of the rest of the muscle and the highest fibres from the sternal body pass into the lowest part of the posterior lamina. The succeeding fibres, after curving backwards, ascend and blend with the posterior lamina, extending it in an upward direction. As a result, the tendon appears to be twisted. The posterior lamina of the tendon reaches higher on the humerus than the anterior, and gives off an expansion which covers the bicipital groove and blends with the capsular ligament of the shoulder joint. From the deepest fibres of this lamina at its insertion an expansion is given off which lines the intertubercular sulcus, while from the lower border of the tendon a third expansion passes downwards to the fascia of the upper arm.

The rounded lower border of the muscle forms the anterior axillary fold and is rendered more conspicuous in the living subject when the abducted arm is adducted against resistance. When the arm is flexed to a right angle, the clavicular head is thrown into contraction, while the sternocostal head is relaxed, but when the flexed arm is extended against resistance, the clavicular head becomes relaxed while the sternocostal head stands out in bold relief.

Relations.—In front, the Pectoralis major is related to the skin, superficial fascia, Platysma, anterior and middle supraclavicular nerves, mammary gland, and deep ascia; its *posterior surface* is in contact with the sternum, ribs and costal cartilages, clavipectoral fascia, Subclavius, Pectoralis minor, Serratus anterior, and Intercostal muscles; it forms the superficial stratum of the anterior wall of the axillary space, and so covers the axillary vessels and nerves and the upper parts of the Biceps and Coracobrachialis. Immediately below the clavicle its *upper border* is separated from the Deltoid muscle by the *infraclavicular fossa*, in which the cephalic vein and deltoid branch of the thoraco-acromial artery lie. Its *lower border* forms the anterior fold of the axilla; it is separated from the Latissimus dorsi by a considerable interval at the medial wall of the axilla, but the two muscles gradually converge towards the lateral wall of the space.

Nerve-supply.—The Pectoralis major is supplied by the lateral and medial pectoral nerves; the fibres for the clavicular part of the muscle are derived from C. 5 and 6, and those for the sternocostal part arise from C. 7, 8, and T. 1.

Actions.—The two parts of the Pectoralis major are capable of acting in combination or they may act independently of each other. Acting as a whole, the muscle takes an active part in the movements of adduction and medial rotation of the humerus and, when the arm has been drawn backwards and laterally, i.e. extended, the Pectoralis major draws it forward and medially. When the arm is flexed, the sternocostal fibres take no part in the movement, which is carried out by the clavicular fibres (*portio attollens*) acting with the anterior fibres of the Deltoid muscle and the Coracobrachialis. When the opposite movement, usually carried out with the assistance of the force of gravitation, is resisted, the sternocostal part (*portio deprimens*) helps the Latissimus dorsi and Teres major to depress the arm. When the raised arms are fixed, e.g. by gripping a branch of a tree, the same combination of muscles operates to draw the trunk upwards and forwards in climbing.

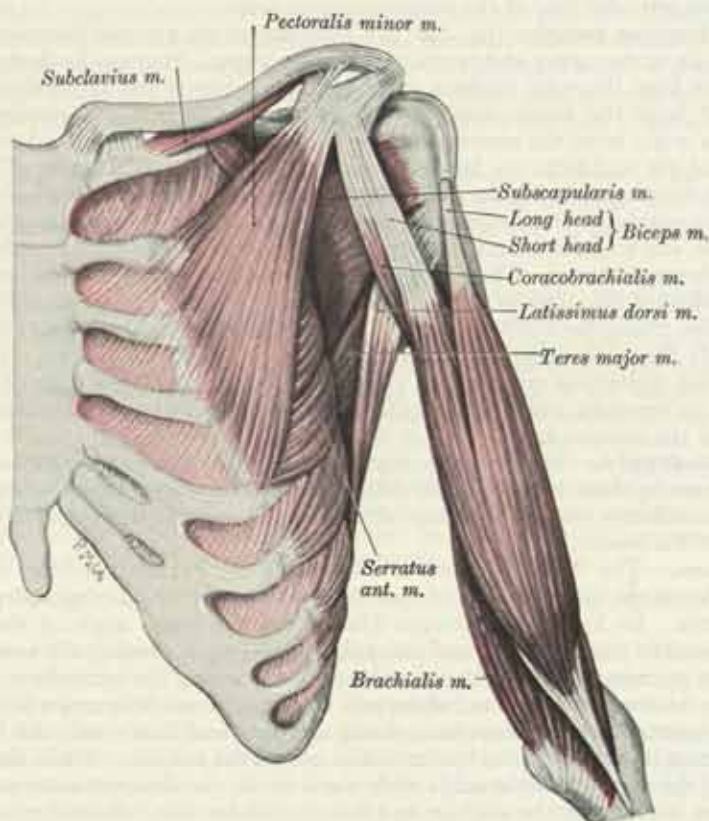
The **clavipectoral fascia** is a strong fibrous sheet situated under cover of the clavicular portion of the Pectoralis major. It occupies the interval between the Pectoralis minor and Subclavius, and covers the axillary vessels and nerves. Traced upwards, it splits to enclose the Subclavius, and is attached to the clavicle, in front of and behind the muscle: the layer behind the muscle fuses with the deep cervical fascia connecting the Omohyoid to the clavicle (see p. 566) and with the sheath of the axillary vessels. Medially, the clavipectoral fascia blends with the fascia covering the first two intercostal spaces, and is attached also to the first rib medial to the origin of the Subclavius. Laterally, it is thick and dense, and is attached to the coracoid process, blending with the coracoclavicular ligament. The portion extending from the first rib to the coracoid process often forms a thickened band,

* G. T. Ashley, *Anat. Rec.*, 113, 1952.

and is sometimes called the *costocoracoid ligament*. Below this, the fascia is thin; it splits to ensheath the Pectoralis minor; and from the lower border of this muscle it is continued downwards to join the axillary fascia, and laterally to unite with the fascia covering the short head of the Biceps. The clavipectoral fascia is pierced by the cephalic vein, thoraco-acromial artery and vein, and lateral pectoral nerve.

The **Pectoralis minor** (fig. 596) is a thin, triangular muscle, situated at the upper part of the thorax, deep to the Pectoralis major. It arises from the upper margins and outer surfaces of the third, fourth and fifth ribs (frequently the second, third and fourth ribs) near their cartilages, and from the fascia covering the External intercostal muscles; the fibres pass upwards and laterally, and converge to form a flat tendon, which is inserted into the medial border and upper surface of the

FIG. 596.—The deep muscles of the front of the chest and arm. Left side.



coracoid process of the scapula. Sometimes a part or the whole of the tendon is continued over the coracoid process and through the coraco-acromial ligament; when this occurs the tendon blends with the coracohumeral ligament and thus gains an attachment to the humerus.

Relations.—Its *anterior surface* is in relation with the Pectoralis major, the lateral pectoral nerve and the pectoral branches of the thoraco-acromial artery; its *posterior surface*, with the ribs, External intercostal muscles, Serratus anterior, the axillary space, the axillary vessels and brachial plexus of nerves. Its *upper border* is separated from the clavicle by a narrow triangular interval occupied by the clavipectoral fascia, behind which are the axillary vessels and nerves. Running parallel with the *lower border* of the muscle is the lateral thoracic artery; piercing and partly supplying the muscle is the medial pectoral nerve.

Nerve-supply.—The Pectoralis minor is supplied by both the pectoral nerves (C. 7 and 8, and T. 1).

Actions.—The Pectoralis minor assists the Serratus anterior to draw the scapula forwards round the chest wall. Acting with the Levator scapulæ and the Rhomboids, the Pectoralis minor rotates the scapula so as to depress the point of the shoulder. When the arm is fixed, it assists in elevating the ribs in forced inspiration.

The **Subclavius** (fig. 596) is a small, triangular muscle, placed between the clavicle and first rib. It arises by a short, thick tendon from the junction of the first rib and its costal cartilage, in front of the costoclavicular ligament; the fleshy fibres proceed obliquely upwards and laterally, to be inserted into the groove on the under surface of the intermediate third of the clavicle.

Relations.—Its *posterior surface* is separated from the first rib by the subclavian vessels and brachial plexus of nerves. Its *anterior surface* is separated from the Pectoralis major by the clavipectoral fascia.

Nerve-supply.—The Subclavius is supplied by a branch which derives its fibres from C. 5 and 6.

Action.—The Subclavius pulls the point of the shoulder downwards and forwards and steadies the clavicle, during movements of the shoulder, by bracing it against the articular disc of the sternoclavicular joint.

The **Serratus anterior** (fig. 596) is a muscular sheet, situated between the ribs and scapula at the upper and lateral parts of the chest. It arises by fleshy slips or digitations from the outer surfaces and superior borders of the upper eight or nine ribs, and from the fasciæ covering the intervening Intercostal muscles. Each digitation arises from the corresponding rib, but the first springs in addition from the second rib, and from the fascia covering the first intercostal space. The lower four slips interdigitate with the upper five slips of the Obliquus externus abdominis. From this extensive attachment the fibres pass backwards, closely applied to the chest-wall, and are inserted into the costal surface of the medial border of the scapula in the following manner. The first digitation is inserted into a triangular area on the costal surface of the superior angle. The next two or three digitations spread out to form a thin, triangular sheet, the base of which is directed backwards and is inserted into nearly the whole length of the costal surface of the medial border. The lower four or five digitations converge to form a fan-shaped mass, the apex of which is inserted, by muscular and tendinous fibres, into a triangular impression on the costal surface of the inferior angle.

Nerve-supply.—The Serratus anterior is supplied by the long thoracic nerve which arises by three roots from the fifth, sixth and seventh cervical nerves (ventral rami) immediately outside the intervertebral foramina and descends on the outer surface of the muscle.

Actions.—The Serratus anterior, acting with the Pectoralis minor, draws the scapula forwards, and is the chief muscle concerned in all pushing and punching movements. Its lower and stronger fibres draw the lower angle of the scapula forwards round the chest wall and assist the Trapezius in rotating the bone. They thus play an important part in the movement of raising the arm above the head (p. 481). In the initial stages of abduction the Serratus anterior acts with the other muscles inserted into the scapula to steady the bone and, as a result, the Deltoid is able to exert its action on the humerus and not on the scapula. While the Deltoid is raising the arm to a right angle with the scapula, the Serratus anterior and the Trapezius are rotating the scapula, and the arm can be raised above the head as the result of this combination of movements. When weights are carried in front of the body, the tone of the Serratus anterior increases in order to prevent backward rotation of the scapula. When the scapula is fixed, the lower part of the muscle will pull upon the ribs, and act as a muscle of inspiration.

Applied Anatomy.—When the Serratus anterior is paralysed, the medial border, and especially the lower angle of the scapula, leave the ribs and stand out prominently on the surface, giving a peculiar 'winged' appearance to the back. The patient is unable to raise the arm or to carry out pushing movements, and attempts to do so are followed by a further projection of the lower angle of the scapula from the back of the thorax.

III. THE MUSCLES OF THE SHOULDER

Deltoides.
Subscapularis.
Supraspinatus.

Infraspinatus.
Teres minor.
Teres major.

The **deep fascia** covering the Deltoid invests the muscle, and sends numerous septa between the fasciculi. In front, it is continuous with the pectoral fascia; behind, where it is thick and strong, with the fascia infraspinata; above, it is

attached to the clavicle, the acromion, and the crest of the spine of the scapula; below, it is continuous with the brachial fascia.

The **Deltoid** (fig. 595) is a thick, triangular muscle, which covers the shoulder joint. It arises from the anterior border and upper surface of the lateral one-third of the clavicle; from the lateral margin and upper surface of the acromion, and from the lower lip of the crest of the spine of the scapula, as far back as the triangular surface at its medial end. The fibres converge towards their insertion, the middle passing vertically, the anterior inclining backwards, and the posterior forwards; they unite in a thick tendon which is inserted into the deltoid tuberosity on the lateral side of the shaft of the humerus. At its insertion the tendon gives off an expansion to the deep fascia of the upper arm. This muscle is remarkably coarse in texture, and the part arising from the acromion consists of oblique fibres; these arise in a bipennate manner from the sides of tendinous septa, generally four in number, which pass downwards from the acromion into the muscle. These oblique fibres are inserted into similar tendinous septa, generally three in number, which ascend from the tendon of insertion of the muscle and alternate with the descending septa. The portions of the muscle arising from the clavicle and spine of the scapula are not arranged in this manner, but are inserted into the margins of the tendon of insertion.

The bulk of the muscle, spread out over the projection formed by the greater tuberosity, accounts for the rounded contour of the normal shoulder, and its limits can be determined accurately through the skin, if the arm is maintained in the position of true abduction (p. 486) against gravity.

Relations.—Its *superficial surface* is in relation with the skin, the superficial and deep fasciæ, Platysma, posterior supraclavicular and lateral brachial cutaneous nerves. Its *deep surface* covers the coracoid process, coraco-acromial ligament, subacromial bursa, the tendon of insertion of the Pectoralis minor, the tendons of origin of the Coracobrachialis and both heads of the Biceps, the tendon of the Pectoralis major, the insertions of the Subscapularis, Supraspinatus, Infraspinatus, and Teres minor, the long and lateral heads of the Triceps, the circumflex humeral vessels, the axillary nerve and the surgical neck and upper part of the shaft of the humerus, including both tuberosities. Its *anterior border* is separated at its upper part from the Pectoralis major by the infraclavicular fossa, in which the cephalic vein and deltoid branch of the thoraco-acromial artery lie; lower down the two muscles are in contact. Its *posterior border* covers the Infraspinatus and Triceps.

Nerve-supply.—The Deltoid muscle is supplied by the axillary nerve (C. 5 and 6).

Actions.—The muscle is capable of acting in parts or as a whole. The anterior fibres co-operate with the Pectoralis major in drawing the arm forwards, and they can act as medial rotators of the humerus. The posterior fibres co-operate with the Latissimus dorsi and the Teres major in drawing the arm backwards and they can act as lateral rotators of the humerus. The multipennate, acromial part is the strongest and most important part of the muscle. Aided by the Supraspinatus it raises the arm from the side until the inferior part of the capsule of the shoulder joint is put on the stretch, *while retaining the humerus in the same plane as the body of the scapula*. This point is of importance because it is only when the humerus lies in the scapular plane that scapular rotation can have its full effect in raising the arm above the head. When the arm is actively maintained in the position of true abduction (p. 486, footnote), the acromial fibres are strongly contracted, but the clavicular and posterior fibres are put on the stretch and function as stays to steady the limb and to prevent side-sway. While the Deltoid is effecting this movement of the humerus on the scapula, the scapula itself is being rotated by the continued actions of the Serratus anterior and the Trapezius. As already stated (p. 487), in the early stages of abduction the traction exerted by the Deltoid muscle is in an upward direction, but the head of the humerus is prevented from gliding upwards on the glenoid cavity by the downward pull of the Subscapularis, Infraspinatus and Teres minor muscles, which come into action synergically with the Deltoid. As a result the Deltoid and Supraspinatus, on the one hand, and the Subscapularis, Infraspinatus and Teres minor, on the other, constitute in effect a mechanical couple which ensures the perfect performance of the movement of abduction (p. 621).

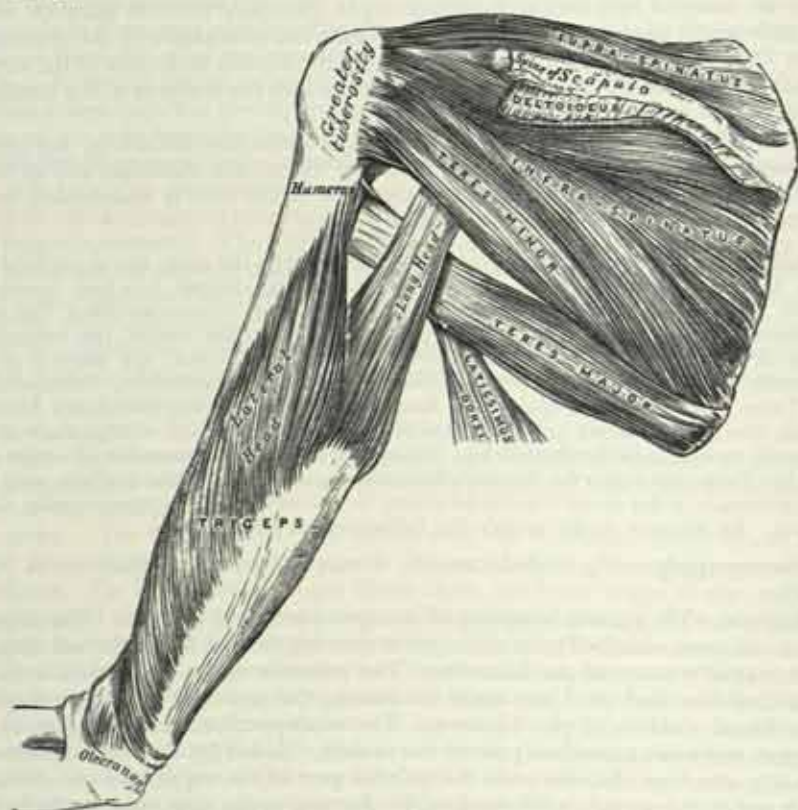
Applied Anatomy.—The Deltoid atrophies after injury to the axillary nerve, and in this condition dislocation of the shoulder joint is simulated, as there is flattening

of the shoulder and apparent prominence of the acromion; the distance between the acromion and the head of the bone is increased also, and the tips of the fingers can be inserted between them.

The **subscapular fascia** is a thin membrane attached to the entire circumference of the subscapular fossa, and giving origin by its deep surface to some of the fibres of the Subscapularis.

The **Subscapularis** (fig. 596) is a large, triangular muscle, which fills the subscapular fossa and arises from its medial two-thirds, including the grooved area adjoining the lateral border of the scapula. Some fibres arise from tendinous laminae which intersect the muscle and are attached to ridges on the bone; others from an aponeurosis which separates the muscle from the Teres major and the long

FIG. 597.—The muscles on the dorsum of the scapula, and the Triceps. Left side.



Note.—The spine of the scapula has been divided near its lateral end and the acromion has been removed together with a large part of the Deltoid muscle.

head of the Triceps. The fibres pass laterally, and, gradually converging, end in a tendon which is inserted into the lesser tuberosity of the humerus and the front of the capsule of the shoulder joint. The tendon of the muscle is separated from the neck of the scapula by a large bursa, which communicates with the cavity of the shoulder joint through an aperture in the fibrous capsule.

Relations.—The *anterior surface* of this muscle forms a considerable part of the posterior wall of the axilla. Its lower and medial two-thirds are in apposition with the Serratus anterior, and its upper and lateral portion is related to the Coracobrachialis and Biceps, the axillary vessels and brachial plexus of nerves, and the subscapular vessels and nerves. Its *posterior surface* is in relation with the scapula and the capsule of the shoulder joint. Its *lower border* is in contact with the Teres major and Latissimus dorsi.

Nerves.—The Subscapularis is supplied by the upper and lower subscapular nerves (C. 5 and 6).

The **fascia supraspinata** completes the osseofibrous case in which the Supraspinatus muscle is contained, and its deep surface gives origin to some of the fibres of the muscle. It is thick medially, but thinner laterally under the coraco-acromial ligament.

The **Supraspinatus** (fig. 597) occupies the supraspinous fossa, arising from its medial two-thirds, and from the fascia supraspinata. The muscular fibres pass under the acromion, and converge to a tendon which crosses the upper part of the shoulder joint and is inserted into the highest of the three impressions on the greater tuberosity of the humerus; at its insertion the tendon is intimately adherent to the capsule of the shoulder joint.

Nerve-supply.—The Supraspinatus is supplied by the suprascapular nerve (C. 5 and 6).

The **fascia infraspinata** covers the Infraspinatus muscle, and is fixed to the borders of the infraspinous fossa; its deep surface gives origin to some fibres of that muscle. It is continuous with the deltoid fascia along the overlapping border of the Deltoid.

The **Infraspinatus** (fig. 597) is a thick triangular muscle, which occupies the chief part of the infraspinous fossa; it arises by fleshy fibres from the medial two-thirds of the fossa, and by tendinous fibres from the ridges on its surface: it also arises from the fascia infraspinata, which covers it and separates it from the Teres major and minor muscles. The fibres converge to a tendon, which glides over the lateral border of the spine of the scapula, and, passing across the posterior part of the capsule of the shoulder joint, is inserted into the middle impression on the greater tuberosity of the humerus. The tendon of this muscle is sometimes separated from the capsule of the shoulder joint by a bursa, which may communicate with the joint cavity.

Nerve-supply.—The Infraspinatus is supplied by the suprascapular nerve (C. 5 and 6).

The **Teres minor** (fig. 597) is a narrow, elongated muscle, which arises from the upper two-thirds of a flattened strip on the lateral part of the dorsal surface of the scapula, immediately adjoining the lateral border, and from two aponeurotic laminae, of which one separates it from the Infraspinatus, and the other from the Teres major muscle. Its fibres run obliquely upwards and laterally; the upper ones end in a tendon which is inserted into the lowest of the three impressions on the greater tuberosity of the humerus; the lower fibres are inserted directly into the humerus immediately below this impression and just above the origin of the lateral head of the Triceps. The tendon of this muscle passes across, and is united with, the lower part of the posterior surface of the capsule of the shoulder joint.

Nerve-supply.—The Teres minor is supplied by the axillary nerve (C. 5).

Actions.—The Subscapularis, Supraspinatus, Infraspinatus and Teres minor come into play during all movements of the arm and their most important function is to produce a stabilising effect on the head of the humerus, retaining it in its correct relationship to the glenoid cavity and controlling its tendency to skid (p. 487). In exercising this postural influence during the initial stages of abduction the Subscapularis, Infraspinatus and Teres minor counteract the strong upward pull of the Deltoid and, aided by the Supraspinatus, enable it to draw the arm away from the body.

In addition, the Infraspinatus and Teres minor, in association with the posterior fibres of the Deltoid, act as lateral rotators of the humerus and the Subscapularis may assist in medial rotation when the arm is by the side.

The **Teres major** (fig. 597) is a thick, somewhat flattened muscle, which arises from the oval area on the dorsal surface of the inferior angle of the scapula, and from the fibrous septa interposed between the muscle and the Teres minor and Infraspinatus; the fibres are directed upwards and laterally and end in a flat tendon, about 5 cm. long, which is inserted into the medial lip of the bicipital groove of the humerus. At its insertion the tendon lies behind the tendon of the Latissimus dorsi muscle, from which it is separated by a bursa, the two tendons being, however, united along their lower borders for a short distance.

Nerve-supply.—The Teres major is supplied by the lower subscapular nerve (C. 5 and 6).

Actions.—The Teres major draws the humerus medially and backwards, and rotates it medially.

IV. THE MUSCLES OF THE UPPER ARM

Coracobrachialis.
Biceps (brachii).

Brachialis.
Triceps.

The **brachial fascia**, or deep fascia of the arm, is continuous with that covering the Deltoid and the Pectoralis major; it forms a thin, loose sheath for the muscles of the upper arm, and sends septa between them; it is composed of fibres disposed in a circular or spiral direction, and connected together by vertical and oblique fibres. It is thin over the Biceps, but thicker where it covers the Triceps, and over the epicondyles of the humerus: it is strengthened by fibrous aponeuroses, derived from the Pectoralis major and Latissimus dorsi medially, and from the Deltoid laterally. On each side it gives off a strong intermuscular septum, which is attached to the corresponding supracondylar ridge and epicondyle of the humerus.

The *lateral intermuscular septum* extends from the lower part of the lateral lip of the bicipital groove, along the lateral supracondylar ridge, to the lateral epicondyle; it is blended with the tendon of the Deltoid, gives attachment to the Triceps behind, to the Brachialis, Brachioradialis and Extensor carpi radialis longus in front, and is perforated at the junction of its upper and middle thirds by the radial nerve and the radial collateral branch of the arteria profunda brachii. The *medial intermuscular septum*, thicker than the preceding, extends from the lower part of the medial lip of the bicipital groove below the Teres major, along the medial supracondylar ridge to the medial epicondyle; it is blended with the tendon of the Coracobrachialis, and affords attachment to the Triceps behind and the Brachialis in front. It is perforated by the ulnar nerve, the superior ulnar collateral artery, and the posterior branch of the inferior ulnar collateral artery.

At the elbow, the brachial fascia is attached to the epicondyles of the humerus and the olecranon of the ulna, and is continuous with the antebrachial fascia. Just below the middle of the medial side of the upper arm, an oval opening in the fascia transmits the basilic vein and some lymphatic vessels.

The **Coracobrachialis** (figs. 596, 598) is situated at the upper and medial part of the arm. It arises from the apex of the coracoid process, in common with the tendon of the short head of the Biceps, and by muscular fibres from the upper 10 cm. of this tendon; it is inserted into an impression, from 3 to 5 cm. in length, at the middle part of the medial border of the shaft of the humerus between the origins of the Triceps and Brachialis. In the living subject the muscle forms an inconspicuous rounded ridge on the upper part of the medial side of the arm, and the pulsations of the brachial artery can be felt in the depression behind it.

Relations.—It is perforated by the musculocutaneous nerve, and is in relation, in front, with the Pectoralis major above, and at its insertion with the brachial vessels and median nerve, which cross it; behind, with the tendons of the Subscapularis, Latissimus dorsi, and Teres major, the medial head of the Triceps, the humerus and the anterior circumflex humeral vessels; by its *medial border*, with the third part of the axillary artery, the upper part of the brachial artery, the median and musculocutaneous nerves; by its *lateral border*, with the Biceps and Brachialis.

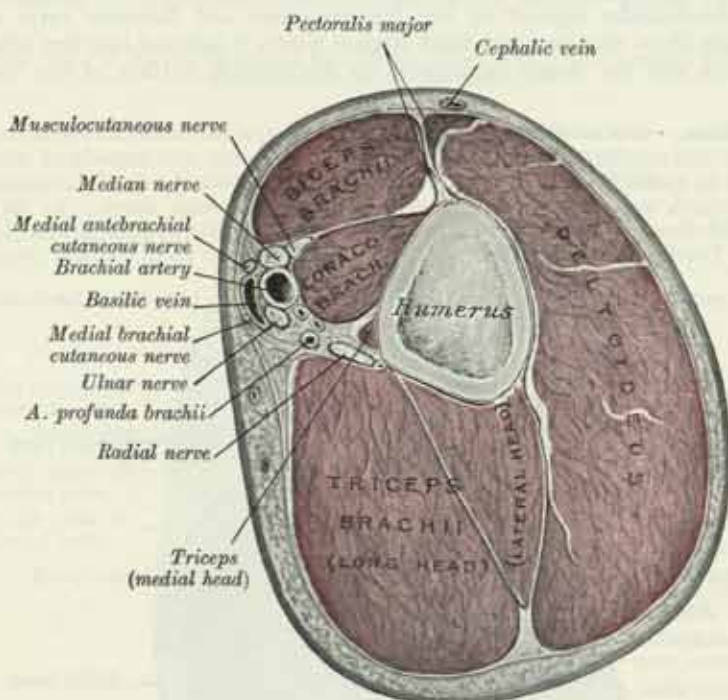
Nerve-supply.—The Coracobrachialis is supplied by the musculocutaneous nerve (C. 7).

Action.—The Coracobrachialis draws the arm forwards and medially and, when the arm is raised from the side, it acts with the anterior fibres of the Deltoid to prevent side-sway (p. 619).

The **Biceps (brachii)** (figs. 596, 598, 599), a long, fusiform muscle placed on the front of the arm, has received its name from the fact that it has two heads of origin. The *short head* arises by a thick flattened tendon from the apex of the coracoid process, in common with the Coracobrachialis. The *long head* takes origin within the fibrous capsule of the shoulder joint. It arises by a long narrow tendon from the supraglenoid tubercle at the apex of the glenoid cavity, and is continuous with the glenoidal labrum (p. 485). The tendon of the long head, enclosed in a sheath of the synovial membrane of the shoulder joint arches over the head of the humerus; it emerges from the joint by passing behind the transverse humeral ligament and then descends in the bicipital groove; it is retained in the groove by the transverse humeral ligament and by a fibrous expansion from the tendon of the Pectoralis major muscle. Each tendon is succeeded by an elongated

muscular belly, and the two bellies, although closely applied to each other, can be readily separated until within about 7.5 cm. of the elbow joint. Here they end in a flattened tendon which is inserted into the rough posterior portion of the tuberosity of the radius, a bursa being interposed between the tendon and the front part of the tuberosity. As the tendon of the muscle approaches the radius it is twisted upon itself, so that its anterior surface becomes lateral and is applied to the tuberosity of the radius at its insertion. Opposite the bend of the elbow the tendon gives off, from its medial side, a broad aponeurosis, named the *bicipital aponeurosis*, which passes obliquely downwards and medially across the brachial artery and is continuous with the deep fascia covering the origins of the flexor muscles of the forearm (fig. 495). With very little force the tendon of insertion can be split down to the radial tuberosity, when it can be seen that the anterior portion of the tendon receives the fibres of the short head, and the posterior portion those of the long head.

FIG. 598.—A transverse section through the upper arm at the junction of the proximal with the middle third of the humerus.



A third head to the Biceps is occasionally found, arising at the upper and medial part of the Brachialis, with which it is blended, and inserted into the bicipital aponeurosis and medial side of the tendon of the muscle; in most cases this additional slip lies behind the brachial artery. In some instances the third head consists of two slips, which pass down, one in front of, the other behind the artery.

Relations.—The Biceps is overlapped above by the Pectoralis major and Deltoid; in the rest of its extent it is superficial, being covered only by the fasciæ and skin, and it forms a conspicuous elevation on the front of the arm. Its long head passes through the shoulder joint, and its short head rests on the joint and on the upper part of the humerus; below, it lies on the Brachialis, the musculocutaneous nerve, and the Supinator. Its *medial border* is in relation with the Coracobrachialis, and overlaps the brachial vessels and median nerve; its *lateral border* is in relation with the Deltoid and Brachioradialis.

Nerve-supply.—The Biceps is supplied by the musculocutaneous nerve (C. 5 and 6), which gives a branch to each belly of the muscle.

Actions.—The Biceps is a powerful supinator of the forearm; it also flexes the elbow joint, and to a slight extent the shoulder joint. Through the bicipital aponeurosis it is a tensor of the antebrachial fascia. The long head exercises downward pressure on the upper end of the humerus and so helps to prevent the head of the bone from gliding upwards under the influence of the Deltoid.

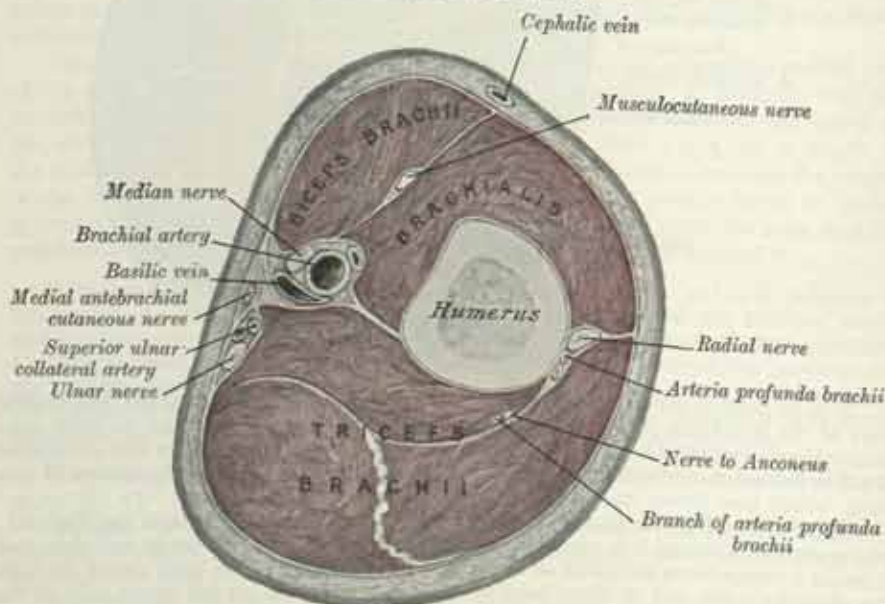
When the elbow is flexed against resistance, the tendon of insertion of the Biceps can be grasped between the finger and thumb and the bicipital aponeurosis can be traced down from its medial edge to the deep fascia covering the origins of the flexor muscles of the forearm.

Applied Anatomy.—The long tendon of the Biceps is sometimes dislocated from its groove on the humerus. When this occurs, the arm is fixed in a position of abduction, but the head of the humerus can be felt in its proper position. The tendon can generally be replaced by flexing the forearm on the arm and rotating the limb. Rupture of the long tendon of the Biceps may also take place.

The **Brachialis** (figs. 596, 599, 600) covers the front of the elbow joint and the lower one-half of the humerus. It arises from the lower one-half of the front of the humerus, commencing above at the insertion of the Deltoid, which it embraces by two pointed processes, and extending below to within 2.5 cm. of the margin of the articular surface. It also arises from the intermuscular septa, but more extensively from the medial than from the lateral; it is separated from the lower part of the lateral intermuscular septum by the Brachioradialis and Extensor carpi radialis longus. Its fibres converge to a thick tendon which is inserted into the tuberosity of the ulna and the rough impression on the anterior surface of the coronoid process.

Relations.—It is in relation, in *front*, with the Biceps, the brachial vessels, musculocutaneous and median nerves; *behind*, with the humerus and capsule of the elbow joint; by its *medial border*, with the Pronator teres, and with the medial intermuscular septum, which separates it from the Triceps and the ulnar nerve; by its *lateral border*, with the radial nerve, radial recurrent and the radial collateral branch of the profunda brachii arteries, the Brachioradialis and Extensor carpi radialis longus.

FIG. 599.—A transverse section through the upper arm, a little below the middle of the shaft of the humerus.



Nerve-supply.—The Brachialis is chiefly supplied by the musculocutaneous nerve (C. 5 and 6), but its lateral part is innervated by the radial nerve (C. 7).

Action.—The Brachialis flexes the elbow joint.

The **Triceps** (figs. 597 to 600), situated on the back of the upper arm, is of large size, and arises by three heads (long, lateral and medial), hence its name.

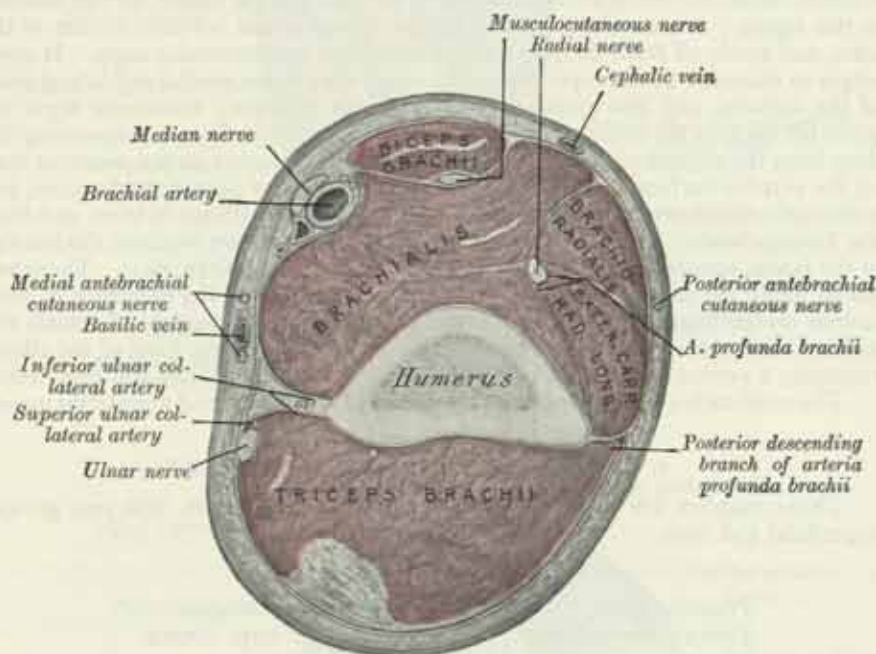
The *long head* arises by a flattened tendon from the infraglenoid tubercle of the scapula, being blended at its upper part with the fibrous capsule of the shoulder joint; the muscular fibres pass downwards along the medial side of the lateral head and superficial to the medial head, and join with them in the tendon of insertion.

The *lateral head* arises from a narrow ridge on the posterior surface of the shaft of the humerus, extending from near the insertion of the *Teres minor* to the upper part of the radial groove, and from the lateral border of the humerus and the lateral intermuscular septum; the fibres from this origin converge towards the tendon of insertion.

The *medial head*, which is covered posteriorly by the lateral and the long heads, arises from the posterior surface of the shaft of the humerus, below the radial groove; it is narrow and pointed above, and extends from the insertion of the *Teres major* to within 2.5 cm. of the trochlea of the humerus; it also arises from the medial border of the bone and from the back of the whole length of the medial intermuscular septum. Some of the fibres are directed downwards to the olecranon, while others converge to the tendon of insertion.

The tendon of insertion of the *Triceps* begins about the middle of the muscle. It consists of two aponeurotic laminae, one of which covers the back of the lower one-half of the muscle; the other is more deeply seated in the substance of the muscle. After receiving the attachment of the muscular fibres, the two lamellae unite above

FIG. 600.—A transverse section through the upper arm, 2 cm. proximal to the medial epicondyle of the humerus.



the elbow, and are inserted, for the most part, into the posterior portion of the upper surface of the olecranon; on the lateral side a band of fibres is continued downwards, over the *Anconeus*, to blend with the antebrachial fascia.

The long head of the *Triceps* descends between the *Teres minor* and *Teres major*, dividing the triangular space between these two muscles and the humerus into two smaller spaces, one triangular, the other quadrangular (fig. 597). The triangular space contains the circumflex scapular vessels; it is bounded by the *Teres minor* above, the *Teres major* below, and the long head of the *Triceps* laterally. The quadrangular space transmits the posterior circumflex humeral vessels and the axillary nerve; it is bounded by the *Subscapularis*, the *Teres minor* and the capsule of the shoulder joint above, the *Teres major* below, the long head of the *Triceps* medially, and the humerus laterally.

The lateral head of the *Triceps* forms an elevation, parallel with and medial to the posterior border of the *Deltoid* muscle; it stands out prominently in the living subject when the elbow is extended actively. The fleshy mass which lies to its medial side, and disappears under cover of the *Deltoid* muscle, is produced by the long head of the *Triceps*.

The **Articularis cubiti (Subanconeus)** is the name given to a few fibres which spring from the deep surface of the lower part of the Triceps, and are inserted into the posterior part of the fibrous capsule of the elbow joint.

Nerves.—The Triceps is supplied by the radial nerve (C. 6, 7, and 8).

Actions.—The Triceps is the great extensor muscle of the forearm. When the arm is extended, the long head of the muscle may assist in drawing the humerus backwards and in adducting it to the thorax. The long head supports the under part of the capsule of the shoulder joint, when the arm is raised from the side. The Articularis cubiti draws up the posterior part of the capsule of the elbow joint during extension of the forearm.

Applied Anatomy.—The insertion of the Triceps into the deep fascia of the forearm is of importance in the operation of excision of the elbow, and should always be carefully preserved. By means of it the patient is enabled to extend the forearm, a movement which would otherwise be accomplished mainly by gravity—that is to say, by allowing the forearm to drop by its own weight.

V. THE MUSCLES OF THE FOREARM

The **antebrachial fascia** (deep fascia of the forearm), continuous above with the brachial fascia, is a dense investment which forms a general sheath for the muscles in this region; it is attached, behind, to the olecranon and posterior border of the ulna, and sends off from its deep surface numerous intermuscular septa. It gives origin to muscular fibres, especially at the upper part of the medial and lateral sides of the forearm, and also ensheathes the different muscles; transverse septa are given off both on the anterior and posterior surfaces of the forearm, separating the deep from the superficial layer of muscles. It is much thicker on the posterior than on the anterior surface, and at the lower than at the upper part of the forearm, and is strengthened above by tendinous fibres derived from the Biceps in front, and from the Triceps behind. In the region of the carpus there are two localised thickenings in the fascia, termed the *flexor* (p. 640) and *extensor retinacula* (p. 641). These two bands retain the digital tendons in position and so increase the efficiency of their actions on the fingers. Apertures exist in the fascia for the passage of vessels and nerves; one of these apertures, of large size and situated at the front of the elbow, transmits a venous communication which connects the superficial and deep veins.

The antebrachial or forearm muscles consist of an anterior and a posterior group.

I. THE ANTERIOR ANTEBRACHIAL MUSCLES

These muscles are divided for convenience of description into two groups, superficial and deep.

(a) *Superficial Group* (fig. 601)

Pronator teres.

Palmaris longus.

Flexor carpi radialis.

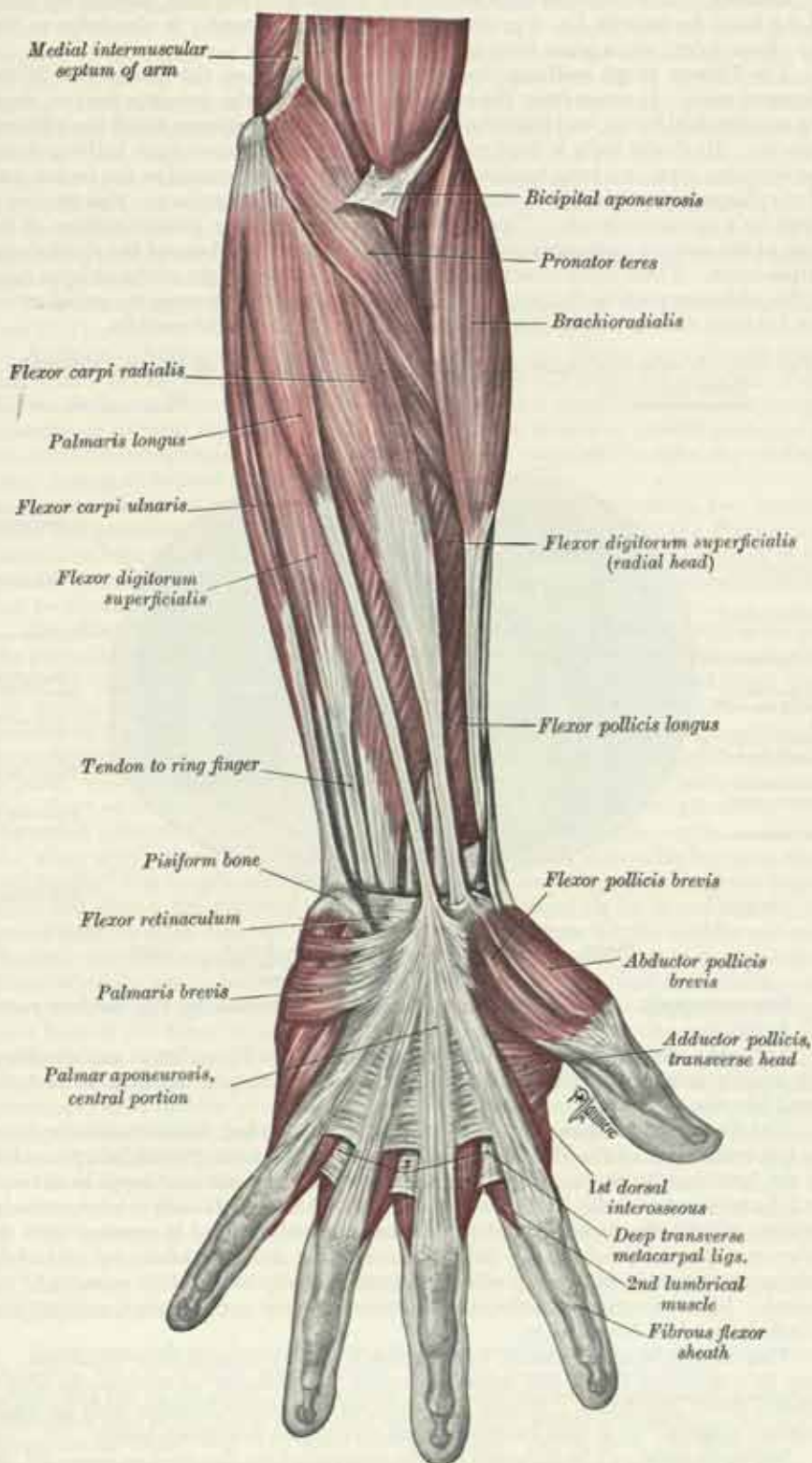
Flexor carpi ulnaris.

Flexor digitorum superficialis.

The muscles of this group take origin from the medial epicondyle of the humerus by a common tendon; they receive additional fibres from the antebrachial fascia near the elbow, and from the septa which pass from this fascia between the individual muscles.

The **Pronator teres** (figs. 601, 602) has a humeral and an ulnar head of origin. The *humeral head*, the larger and more superficial, arises immediately above the medial epicondyle, and from the tendon common to the origin of the other muscles; also from the intermuscular septum between it and the Flexor carpi radialis and from the antebrachial fascia. The much smaller *ulnar head* arises from the medial side of the coronoid process of the ulna below the origin of the flexor digitorum superficialis, and joins the humeral head at an acute angle. The median nerve enters the forearm between the heads of the muscle, and is separated from the ulnar artery by the ulnar head. The muscle passes obliquely across the forearm and ends in a flat tendon, which is inserted into a rough impression on the middle of the lateral surface of the shaft of the radius. The lateral border of the muscle forms the medial boundary of the triangular hollow which is situated in front of the elbow joint and is termed the *cubital fossa*.

FIG. 601.—The superficial flexor muscles of the left forearm, the palmar aponeurosis and the digital fibrous flexor sheaths.

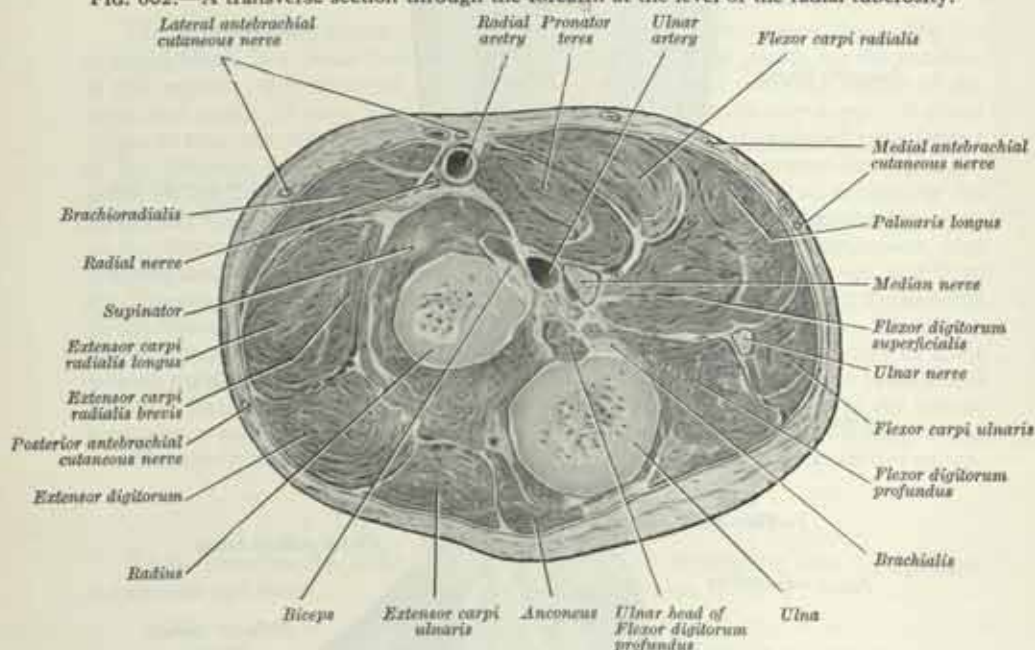


Nerve-supply.—The Pronator teres is supplied by the median nerve (C. 6 and 7).

Actions.—The Pronator teres rotates the radius upon the ulna, turning the palm of the hand backwards, i.e. it pronates the forearm and hand; it also helps to flex the elbow joint, when great force is required.

The **Flexor carpi radialis** (figs. 601, 602, 605) lies on the medial side of the Pronator teres. It arises from the medial epicondyle by the common tendon, from the antebrachial fascia, and from the intermuscular septa between it and the adjacent muscles. Its fleshy belly is fusiform in shape and, rather more than halfway down the forearm, ends in a long tendon, which passes through a canal in the lateral part of the flexor retinaculum and occupies a groove on the trapezium; this groove is lined by a synovial sheath. The tendon is inserted into the palmar surface of the base of the second metacarpal bone, and sends a slip to the base of the third metacarpal bone. These bony attachments are hidden by the origin of the oblique head of the adductor pollicis (fig. 617). In the lower part of the forearm the radial artery lies between the tendon of this muscle and that of the Brachioradialis.

FIG. 602.—A transverse section through the forearm at the level of the radial tuberosity.



Nerve-supply.—The Flexor carpi radialis is supplied by the median nerve (C. 6 and 7).

Actions.—Acting with the Flexor carpi ulnaris, the Flexor carpi radialis flexes the wrist; acting with the radial extensors of the wrist, it helps to abduct the hand (see also p. 634).

The **Palmaris longus** (figs. 601, 602, 616) is a slender, fusiform muscle, lying on the medial side of the Flexor carpi radialis. It arises from the medial epicondyle of the humerus by the common tendon, from the intermuscular septa between it and the adjacent muscles, and from the antebrachial fascia. It ends in a long slender tendon, which passes in front of the flexor retinaculum, and is inserted into the anterior surface of the distal one-half of this structure and into the central part of the palmar aponeurosis, frequently sending a tendinous slip to the short muscles of the thumb. Just above the wrist the median nerve lies deep to the tendon, and projects a little beyond its lateral edge.

This muscle is often absent, and is subject to very considerable variations: it may be tendinous above and muscular below, or muscular in the middle with a tendon above and below; it may consist of two muscular bundles with an intermediate tendon; or it may be represented solely by a tendinous band.

Nerve-supply.—The Palmaris longus is supplied by the median nerve (C. 8).

Actions.—The Palmaris longus flexes the wrist.

The **Flexor carpi ulnaris** (figs. 601, 602, 605) lies along the ulnar side of the forearm. It arises by two heads, humeral and ulnar, connected by a tendinous arch, beneath which the ulnar nerve passes downwards and the posterior ulnar recurrent artery upwards. The *humeral head* is very small and arises from the medial epicondyle of the humerus by the common tendon; the *ulnar head* arises from the medial margin of the olecranon, and from the upper two-thirds of the posterior border of the ulna by an aponeurosis common to it and the Extensor carpi ulnaris and Flexor digitorum profundus, and from the intermuscular septum between it and the Flexor digitorum superficialis. The fibres end in a tendon which is formed along the anterolateral border of the muscle in its distal one-half and is inserted into the pisiform bone, whence it is prolonged to the hamate and fifth metacarpal bones by the pisohamate and pisometacarpal ligaments (p. 499); it is also attached by a few fibres to the flexor retinaculum. The ulnar vessels and nerve lie on the lateral side of its tendon of insertion.

Nerve-supply.—The Flexor carpi ulnaris is supplied by the ulnar nerve (C. 8 and T. 1).

Actions.—Acting with the Flexor carpi radialis, the Flexor carpi ulnaris flexes the wrist; acting with the Extensor carpi ulnaris, it is a powerful adductor of the hand. Both the Flexor and the Extensor carpi ulnaris come into play, as synergic muscles, to prevent abduction of the hand when the thumb is actively extended at its carpo-metacarpal joint. In addition, the Flexor carpi ulnaris fixes the pisiform bone during abduction of the little finger.

In the living subject, when the wrist is flexed against resistance, two tendons stand out prominently on its anterior aspect; the more lateral is the Flexor carpi radialis and the more medial is the Palmaris longus, which lies approximately in the middle line of the limb. On the ulnar side, the tendon of the Flexor carpi ulnaris can be identified proximal to the pisiform bone.

The **Flexor digitorum superficialis** (*sublimis*) (figs. 601, 602, 605) is deep to the preceding muscles; it is the largest of the muscles of the superficial group, and arises by two heads, humero-ulnar and radial. The *humero-ulnar head* arises from the medial epicondyle of the humerus by the common tendon, from the anterior portion of the ulnar collateral ligament of the elbow joint, from the intermuscular septa between it and the preceding muscles, and from the medial side of the coronoid process, above the ulnar origin of the Pronator teres. The *radial head*, which is a thin sheet of muscle, arises from the anterior border of the radius, extending from the radial tuberosity to the insertion of the Pronator teres. The median nerve and the ulnar artery pass downwards through the gap which intervenes between these two heads. The muscle speedily separates into two strata of muscular fibres, superficial and deep; the superficial stratum, which is joined on its lateral side by the radial head, divides into two parts, which end in tendons for the middle and ring fingers; the deep stratum gives off a muscular slip to join that part of the superficial plane which is associated with the tendon of the ring finger, and then divides into two parts, which end in tendons for the index and little fingers. As the four tendons pass behind the flexor retinaculum, they are arranged in pairs, the superficial pair going to the middle and ring, the deep pair to the index and little fingers. The tendons diverge from one another in the palm and opposite the bases of the proximal phalanges each divides into two slips, to allow of the passage of the corresponding tendon of the Flexor digitorum profundus; the surfaces of the two slips become reversed and they then reunite, partially decussate, and so form a grooved channel for the lodgment of the tendon of the Flexor digitorum profundus. Finally the tendon divides and is inserted into the sides of the shaft of the middle phalanx.

Nerve-supply.—The Flexor digitorum superficialis is supplied by the median nerve (C. 7 and 8 and T. 1).

Actions.—The Flexor digitorum superficialis flexes first the middle and then the proximal phalanges. It can also act as a flexor of the wrist.

Relations.—*In the forearm.* The Flexor digitorum superficialis is covered by the Palmaris longus, Flexor carpi radialis, Pronator teres, Brachioradialis, the radial artery and the radial nerve. It is placed in front of the Flexor digitorum profundus, the upper part of the ulnar artery, the median nerve (which is closely bound to it by fibro-areolar tissue) and the Flexor pollicis longus. *At the wrist,* the tendons of the Flexor digitorum superficialis pass behind the flexor retinaculum, lying in front of the tendons of the Flexor digitorum profundus and sharing a common synovial sheath

with them (fig. 613). The Flexor pollicis longus tendon and the median nerve lie to their lateral side. In the hand, the tendons lie behind the palmar aponeurosis, the superficial palmar arch and the digital branches of the median and ulnar nerves, but in front of the tendons of the Flexor digitorum profundus and the lumbrical muscles.

(b) *Deep Group* (fig. 603)

Flexor digitorum profundus.

Flexor pollicis longus.

Pronator quadratus.

The **Flexor digitorum profundus** (figs. 602, 603, 605) is situated on the ulnar side of the forearm, deep to the superficial flexors. It arises from the upper three-fourths of the anterior and medial surfaces of the shaft of the ulna, embracing the insertion of the Brachialis above, and extending to within a short distance of the Pronator quadratus below. It also arises from a depression on the medial side of the coronoid process of the ulna, and from the upper three-fourths of the posterior border of the bone by an aponeurosis, in common with the Flexor and Extensor carpi ulnaris; it also springs from the anterior surface of the ulnar half of the interosseous membrane. The muscle ends in four tendons, which run behind the flexor retinaculum deep to the tendons of the Flexor digitorum superficialis. The portion of the muscle for the index finger is usually distinct throughout, but the tendons for the middle, ring and little fingers are connected together by areolar tissue and tendinous slips, as far as the palm of the hand. Opposite the proximal phalanges the tendons pass through the openings in the tendons of the Flexor digitorum superficialis and they are inserted into the palmar surfaces of the bases of the distal phalanges.

The Flexor digitorum profundus is responsible for the bulk of the fleshy elevation which can be seen in the living subject on the dorsum of the forearm to the medial side of the subcutaneous dorsal border of the ulna.

Nerve-supply.—The medial part of the Flexor digitorum profundus is supplied by the ulnar nerve and its lateral part by the anterior interosseous branch of the median nerve (C. 8 and T. 1).

Actions.—The Flexor digitorum profundus flexes the distal phalanges, after the Flexor digitorum superficialis has bent the middle phalanges; it can also assist in flexing the wrist.

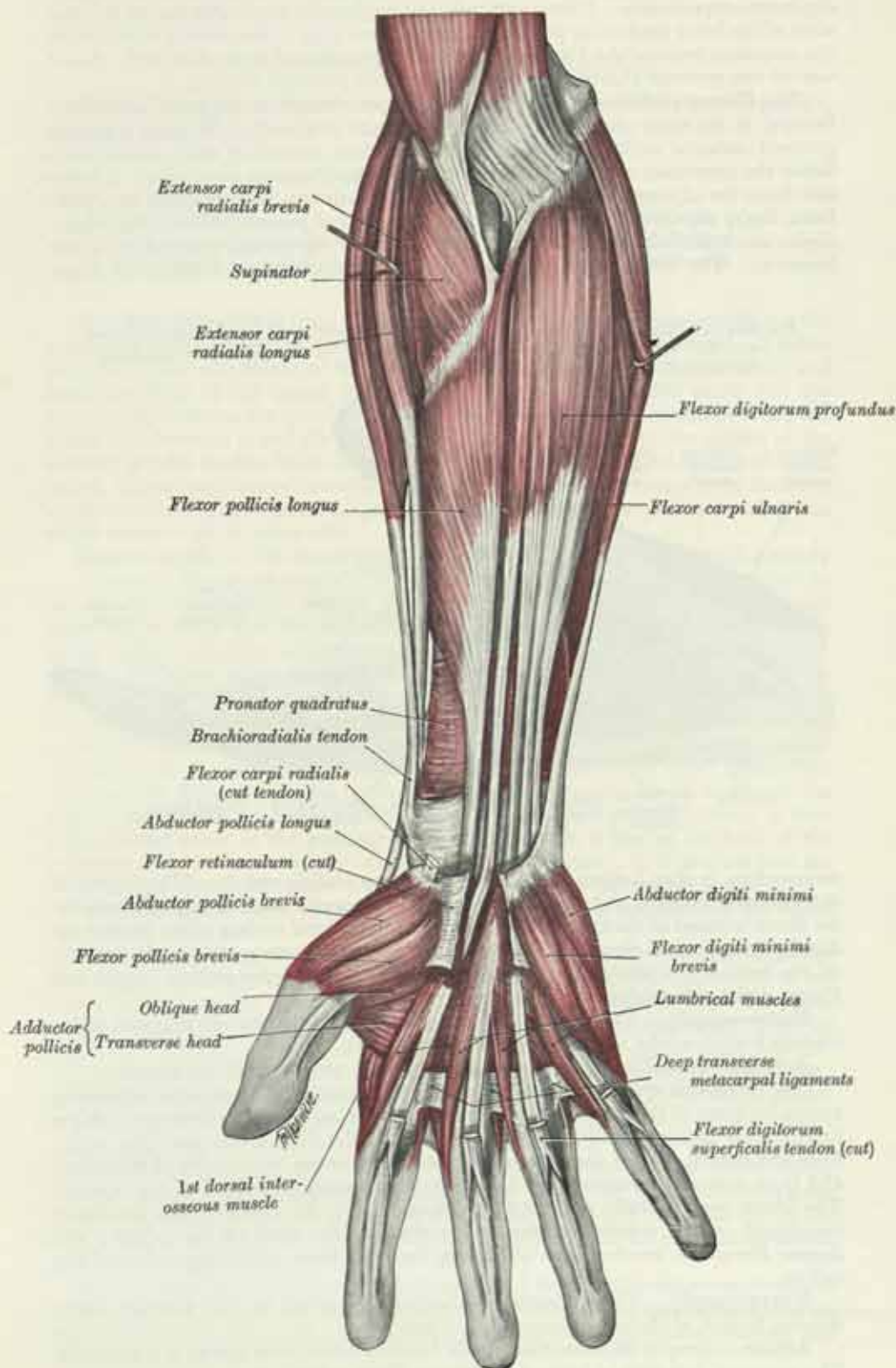
Four small muscles, named the Lumbricales, are connected with the tendons of the Flexor digitorum profundus in the palm, and are described with the muscles of the hand (p. 649).

Fibrous sheaths of the flexor tendons.—After leaving the palm, the tendons of the Flexores digitorum superficialis et profundus lie in osseo-aponeurotic canals (figs. 614, 616), formed behind by the phalanges, and in front by fibrous bands, the *digital fibrous sheaths* which arch across the tendons, and are attached on each side to the margins of the phalanges and to the palmar ligaments of the interphalangeal joints. Opposite the middle of the proximal and middle phalanges the bands are very strong, and the fibres are transverse (*anular part*); but opposite the joints they are much thinner, and consist of oblique fibres (*cruciform part*). Each canal is lined by a synovial sheath, which is reflected on to the contained tendons.

As the flexor tendons approach their insertions they are connected to the dorsal parts of the enclosing synovial sheaths by triangular and thread-like bands of synovial membrane. These bands, termed *vincula tendinum* (fig. 604), convey minute vessels to the tendons, and are of two kinds, (a) *vincula brevia* and (b) *vincula longa*.

The *vincula brevia*, two in number in each finger, are triangular bands attached to the deep surfaces of the tendons close to their insertions; one connects the tendon of the Flexor digitorum superficialis to the front of the proximal interphalangeal joint and adjacent part of the proximal phalanx, and the other the tendon of the Flexor digitorum profundus to the front of the distal interphalangeal joint and adjacent part of the middle phalanx. The *vincula longa* are thread-like slips, of which two are usually attached to each tendon of the Flexor digitorum superficialis, and one to each tendon of the Flexor digitorum profundus. Those of the Flexor digitorum superficialis are connected to the slips of that tendon where these fold over the tendon of the Flexor digitorum profundus, and, passing one on each side of the latter tendon, are attached to the sheath at the lateral margins of the proximal

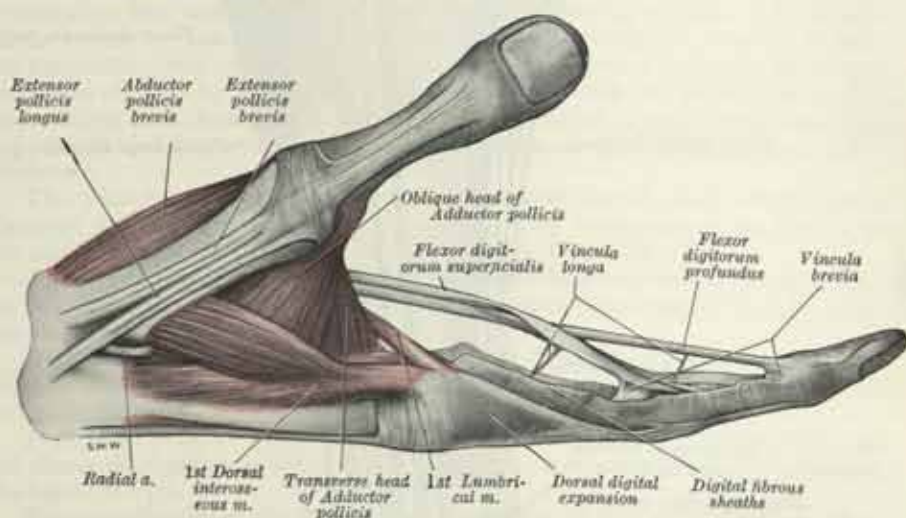
FIG. 603.—The deep muscles of the front of the right forearm.



end of the proximal phalanx. That of the tendon of the *Flexor digitorum profundus* is fixed to its tendon shortly after the latter has pierced the tendon of the *Flexor digitorum superficialis*. It runs upwards and backwards, perforates one of the two slips of the latter tendon, or passes between the two slips; thereafter it blends with the *vinculum breve* of the *Flexor digitorum superficialis* and is attached to the dorsal wall of the synovial sheath at the distal end of the proximal phalanx.

The ***Flexor pollicis longus*** (figs. 603, 613) is situated on the radial side of the forearm in the same plane as the *Flexor digitorum profundus*. It arises from the grooved, anterior surface of the shaft of the radius, extending from immediately below the tuberosity to within a short distance of the *Pronator quadratus*. It arises also from the adjacent part of the interosseous membrane, and generally by a fusiform, fleshy slip from the medial border of the coronoid process, distal to the *Flexor digitorum superficialis* and *Pronator teres*, or from the medial epicondyle of the humerus. The fibres end in a flattened tendon, which passes behind the flexor

FIG. 604.—A dissection of the lateral portion of the right hand showing the tendons and the vincula tendinum of the index finger and the muscles in the first inter-metacarpal space.



retinaculum, is then lodged between the *opponens pollicis* and the oblique head of the *Adductor pollicis*, and, entering an osseo-aponeurotic canal similar to those for the flexor tendons of the fingers, is inserted into the palmar surface of the base of the distal phalanx of the thumb. The anterior interosseous nerve and vessels descend on the front of the interosseous membrane between the *Flexor pollicis longus* and *Flexor digitorum profundus*.

Nerve-supply.—The *Flexor pollicis longus* is supplied by the anterior interosseous branch of the median nerve (C. 8 and T. 1).

Actions.—The *Flexor pollicis longus* flexes the phalanges of the thumb.

The ***Pronator quadratus*** (fig. 603) is a flat, quadrilateral muscle, extending across the front of the lower parts of the radius and ulna. It arises from the oblique ridge on the lower part of the anterior surface of the shaft of the ulna (fig. 393); from the medial part of the anterior surface of the lower one-fourth of the ulna; and from a strong aponeurosis which covers the medial one-third of the muscle. The fibres pass laterally and slightly downwards, to be inserted into the lower one-fourth of the anterior border and surface of the shaft of the radius; the deeper fibres are inserted into the triangular area above the ulnar notch of the radius.

Nerve-supply.—The *Pronator quadratus* is supplied by the anterior interosseous branch of the median nerve (C. 6 and 7).

Action.—Despite its name this muscle has only a very weak action as a pronator. The principal function, at least of the deeper fibres, would appear to be to prevent separation of the lower ends of the radius and ulna when upward thrusts are trans-

mitted through the carpus. Such thrusts result not only from falls or blows on the outstretched hand but also from the pull of the flexor muscles of the wrist and fingers.

2. THE POSTERIOR ANTEBRACHIAL MUSCLES

These muscles are divided for convenience of description into two groups, superficial and deep.

(a) *Superficial Group* (fig. 609)

Brachioradialis.	Extensor digitorum.
Extensor carpi radialis longus.	Extensor digiti minimi.
Extensor carpi radialis brevis.	Extensor carpi ulnaris.
Anconeus.	

The **Brachioradialis** (figs. 601, 602, 605) is the most superficial muscle on the radial side of the forearm and forms the lateral border of the cubital fossa. It arises from the upper two-thirds of the lateral supracondylar ridge of the humerus, and from the front of the lateral intermuscular septum. The radial nerve and the anastomosis between the arteria profunda brachii and the radial recurrent artery are interposed between it and the Brachialis. The fibres end above the middle of the forearm in a flat tendon which is inserted into the lateral side of the lower end of the radius, immediately above the styloid process. The tendon is crossed at its insertion by the tendons of the Abductor pollicis longus and Extensor pollicis brevis; the radial artery is on its ulnar side.

Nerve-supply.—The Brachioradialis is supplied by the radial nerve (C. 5 and 6).

Action.—The Brachioradialis is a flexor of the elbow joint, but is supplied by the nerve of the extensor muscles, i.e. the radial nerve. It acts to best advantage when the forearm is in the midprone position and stands out prominently in the living subject when the semi-pronated forearm is flexed against resistance.

The **Extensor carpi radialis longus** (figs. 605, 609) is partly covered by the Brachioradialis. It arises mainly from the lower one-third of the lateral supracondylar ridge of the humerus and from the front of the lateral intermuscular septum, but it receives a few fibres from the common tendon of origin of the extensor muscles of the forearm. The muscle ends at the junction of the upper and middle thirds of the forearm in a flat tendon, which runs along the lateral border of the radius, deep to the Abductor pollicis longus and Extensor pollicis brevis; it then passes under cover of the extensor retinaculum, where it lies on the back of the radius in a groove immediately behind the styloid process. It is inserted into the radial side of the dorsal surface of the base of the second metacarpal bone.

Nerve-supply.—The Extensor carpi radialis longus is supplied by the radial nerve (C. 6 and 7).

The **Extensor carpi radialis brevis** (figs. 605, 609, 613) is shorter than the preceding muscle and is covered by it. It arises from the lateral epicondyle of the humerus, by a tendon common to it and the next three muscles; from the radial collateral ligament of the elbow joint; from a strong aponeurosis which covers its surface; and from the intermuscular septa between it and the adjacent muscles. The fibres end about the middle of the forearm in a flat tendon which closely accompanies that of the preceding muscle to the wrist; it passes deep to the Abductor pollicis longus and Extensor pollicis brevis muscles, then under cover of the extensor retinaculum, and is inserted into the dorsal surface of the base of the third metacarpal bone, on its radial side and distal to its styloid process, and into the adjoining part of the base of the second metacarpal bone. Under the extensor retinaculum the tendon lies on the back of the radius in a shallow groove, on the ulnar side of the groove which lodges the tendon of the Extensor carpi radialis longus, and separated from it by a faint ridge.

The tendons of the two preceding muscles pass through the same compartment of the extensor retinaculum in a single synovial sheath. They can be identified on the back of the carpus in the living subject, when the fist is alternately clenched and relaxed.

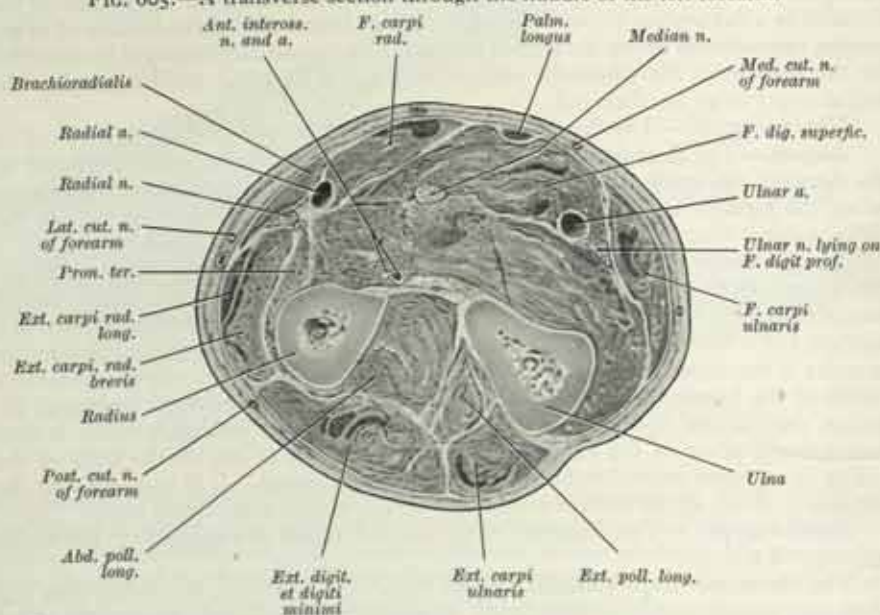
Nerve-supply.—The Extensor carpi radialis brevis is supplied by the posterior interosseous nerve (C. 6 and 7).

Actions.—Both the preceding muscles act synergically with the flexors of the fingers, and this action can readily be appreciated when the fist is clenched. Working with the Extensor carpi ulnaris, they extend the wrist; working with the Flexor carpi radialis, they abduct the hand. It should be noted that they are much oftener called into action as synergic muscles than as prime movers.

The **Extensor digitorum** (figs. 605, 609, 613) arises from the lateral epicondyle of the humerus by the common tendon; from the intermuscular septa between it and the adjacent muscles, and from the antebrachial fascia. It divides below into four tendons, which pass, together with that of the Extensor indicis, through a compartment of the extensor retinaculum, within a common synovial sheath. The tendons then diverge on the dorsum of the hand, each proceeding to its own digit. The tendon to the index finger is accompanied by the Extensor indicis, which lies on its ulnar side. On the back of the hand, the tendons to the middle, ring and little fingers are connected by two obliquely placed bands, the *intertendinous connexions*, one from the third tendon passing downwards and laterally to the second tendon, and the other passing from the fourth to the third. Occasionally the second tendon is similarly connected to the first.

The insertion of these tendons is complicated by the presence, on the dorsum of the proximal phalanx, of a fibrous expansion in the formation of which the lumbrical, interosseous and digital extensor tendons all participate.

FIG. 605.—A transverse section through the middle of the left forearm.



The *dorsal digital expansion* is a fibrous membrane which covers the dorsum of the proximal phalanx and the sides of its base. It is triangular in shape and its base, which is placed proximally, is closely applied to the dorsal and collateral aspects of the metacarpophalangeal joint, when the digit is extended. The extensor digitorum tendon lies in the middle of the expansion, with which it is blended, and is separated from the metacarpophalangeal joint by a small bursa (fig. 606). The base of the expansion connects the extensor digitorum tendon on each side to the corresponding interosseous muscle, and is marked by numerous transverse fibres. Between the tendon of the lumbrical and the adjoining interosseous muscle a short band binds the lateral basal angle of the expansion to the deep transverse metacarpal ligament.

The lateral border of the expansion is thickened and is formed by the tendon of the lumbrical muscle on the lateral side and by the tendon of the corresponding interosseous muscle on the medial side. Between it and the extensor digitorum tendon the expansion takes the form of a thin, translucent sheet (fig. 606). As it approaches the proximal interphalangeal joint the extensor digitorum tendon divides into an intermediate part and two collateral slips. The former passes over the dorsal aspect of the joint to be inserted into the base of the middle phalanx. Each collateral slip is joined by the corresponding thickened border of the dorsal

digital expansion, and the two then converge and unite to be inserted into the dorsal aspect of the base of the distal phalanx.

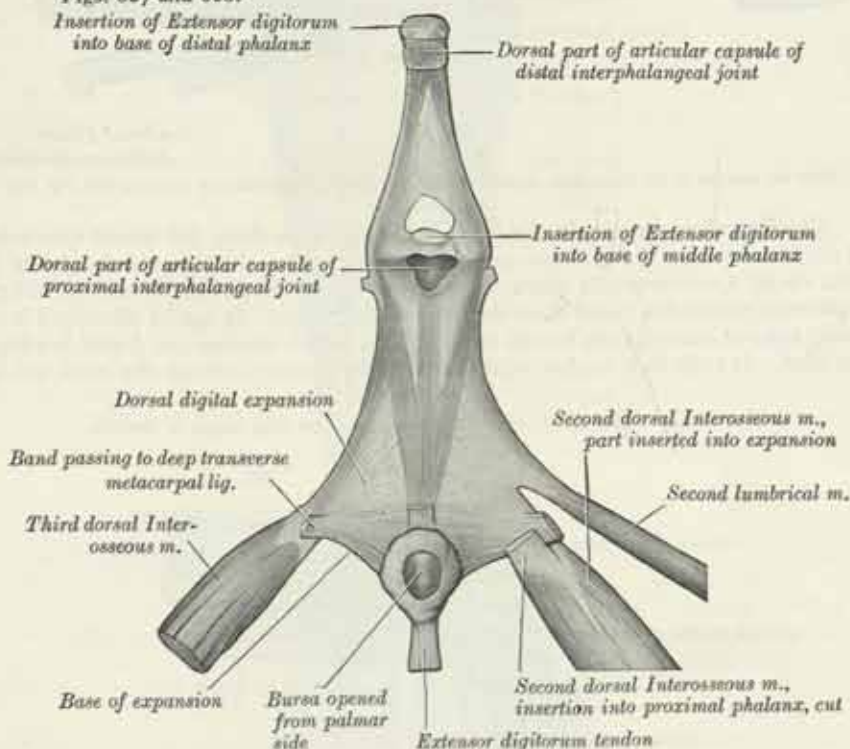
The expansion forms a movable hood,* which passes distally when the metacarpophalangeal joint is flexed, and proximally when it is extended.

Nerve-supply.—The Extensor digitorum is supplied by the posterior interosseous nerve (C. 7 and 8).

Actions.—The extensor digitorum extends the fingers at the metacarpophalangeal and interphalangeal joints in opening the hand and relaxing the grip. When necessary, it can assist in extending the wrist. It tends to abduct the index, ring and little fingers as it extends them, but it has no corresponding action on the middle finger.

When the movement of flexion of the metacarpophalangeal joint is combined with extension of the interphalangeal joints, as in the upstroke in writing or in

FIG. 606.—The dorsal digital expansion of the middle finger, showing its connexions. Viewed from the palmar surface, the basal angles having been drawn out and the whole expansion kept taut and flattened. Compare with Figs. 607 and 608.



Immediately distal to the bursa which overlies the metacarpophalangeal joint, a small slip from the extensor digitorum tendon is inserted into the base of the proximal phalanx. This slip, which is not always present, is shown cut, but is not labelled.

threading a needle (male fashion), the movement of flexion, for which the lumbricals and interossei are responsible, effects sufficient relaxation of the digital flexors to enable the extensor digitorum to extend the interphalangeal joints by virtue of its normal tonus.† It should be noted, however, that the interossei, working over the distal border of the deep transverse metacarpal ligaments, are not disadvantageously placed to produce extension of the interphalangeal joints through the medium of the dorsal digital expansion, and can in fact be trained to do so in cases of radial palsy.

The **Extensor digiti minimi** (fig. 609) is a slender muscle, placed medial to, and usually connected with, the Extensor digitorum muscle. It arises from the common extensor tendon by a thin tendinous slip, and from the intermuscular septa between it and the adjacent muscles. Its tendon runs through a separate compartment of the extensor retinaculum behind the inferior radio-ulnar joint, then divides

* S. Bunnell, *Surgery of the Hand*, J. B. Lippincott Co., 2nd edition, 1949.

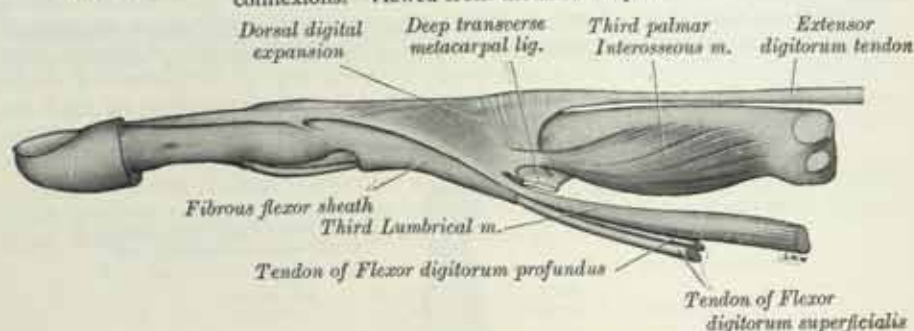
† F. Braithwaite, G. D. Channell F. T. Moore and J. Whillis, *Guy's Hosp. Rep.*, 97, 1948.

into two parts which re-unite near the head of the fifth metacarpal bone and are then joined laterally by a slip from the extensor digitorum (fig. 609). The dorsal digital expansion on the proximal phalanx of the fifth digit conforms to the description already given (p. 634).

Nerve-supply.—The Extensor digiti minimi is supplied by the posterior interosseous nerve (C. 7).

Actions.—The Extensor digiti minimi extends the little finger and can assist in extending the wrist.

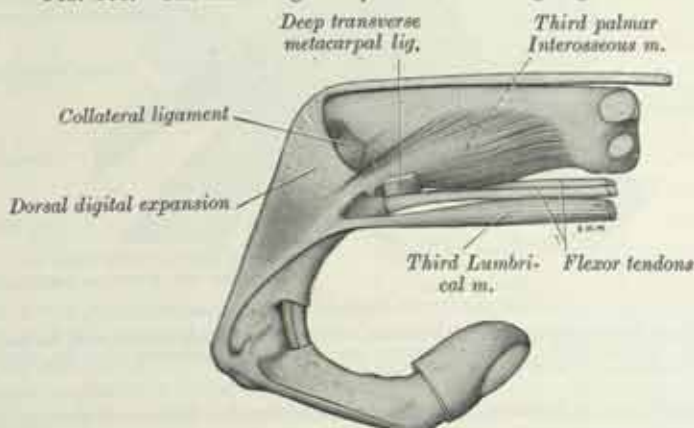
FIG. 607.—The ring finger dissected to show the dorsal digital expansion and its connexions. Viewed from the lateral aspect.



Note the position of the base of the expansion when the finger is extended and compare with Fig. 608.

The **Extensor carpi ulnaris** (figs. 605, 609) arises from the lateral epicondyle of the humerus, by the common extensor tendon; from the posterior border of the ulna by an aponeurosis in common with the Flexor carpi ulnaris and the Flexor digitorum profundus; and from the antebrachial fascia. It can be identified in the living subject immediately lateral to the groove which overlies the dorsal border of the ulna. It ends in a tendon which runs in the groove between the head and the

FIG. 608.—The dorsal digital expansion of the ring finger in flexion.



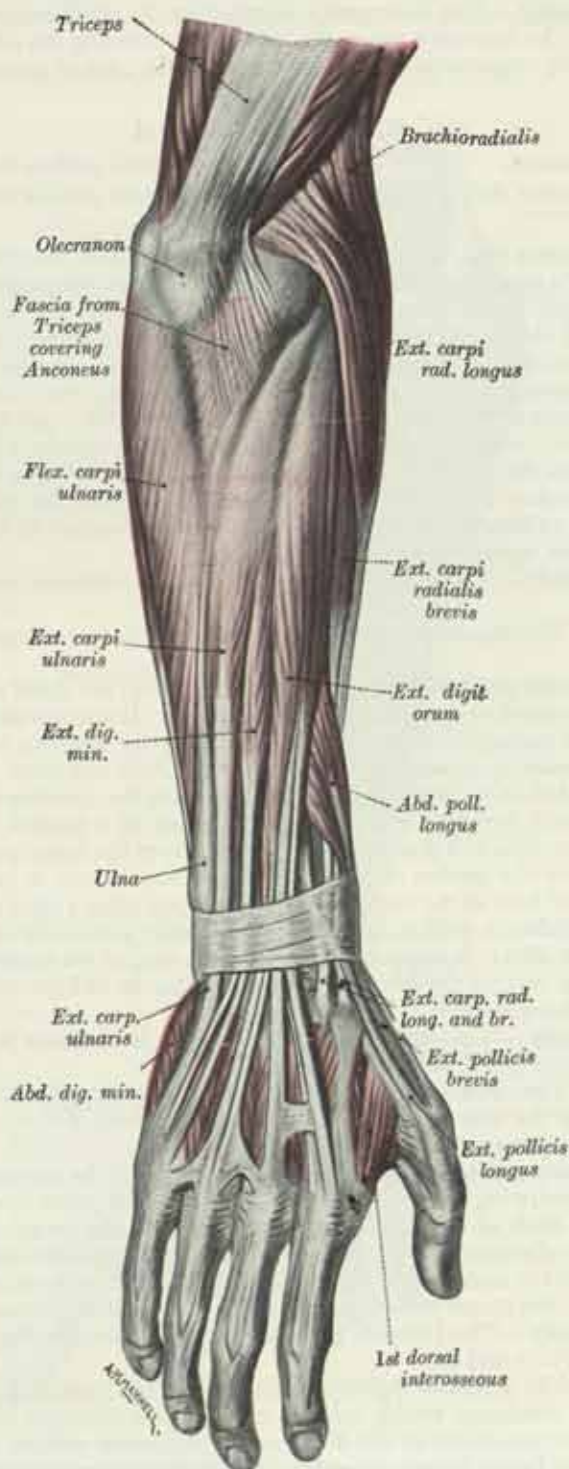
Compare with fig. 607, and note that the base of the expansion has moved distally.

styloid process of the ulna, passing through a separate compartment of the extensor retinaculum, and is inserted into the tubercle on the ulnar side of the base of the fifth metacarpal bone.

Nerve-supply.—The Extensor carpi ulnaris is supplied by the posterior interosseous nerve (C. 7 and 8).

Actions.—In association with the Extensores carpi radiales, longus et brevis, the Extensor carpi ulnaris acts synergically with the flexors of the fingers in order to steady the wrist when objects are being gripped or when the fist is clenched. Acting with the Extensores carpi radiales, it extends the wrist; acting with the Flexor carpi ulnaris, it adducts the hand.

FIG. 609.—Muscles of extensor aspect of forearm, superficial layer.
(From Quain's *Anatomy*, XI. Edition.)



The **Anconeus** (figs. 609, 610) is a small, triangular muscle on the back of the elbow joint, and appears to be a continuation of the Triceps. It arises by a separate tendon from the posterior surface of the lateral epicondyle of the humerus; its fibres diverge as they pass medially to reach the ulna, covering the posterior aspect

of the anular ligament. They are inserted into the lateral side of the olecranon, and upper one-fourth of the posterior surface of the shaft of the ulna.

Nerve-supply.—The Anconeus is supplied by the radial nerve (C. 7 and 8).

Action.—The Anconeus assists the Triceps in extending the elbow joint and is, probably, partly responsible for the movement of the ulna in pronation.

(b) *Deep Group* (fig. 610)

Supinator.	Extensor pollicis brevis.
Abductor pollicis longus.	Extensor pollicis longus.
	Extensor indicis.

The **Supinator** (figs. 603, 610, 611) surrounds the upper one-third of the radius, and consists of a superficial and a deep part, between which the posterior interosseous nerve passes (fig. 610). The two parts arise in common—the superficial one by tendinous and the deeper by muscular fibres—from the lateral epicondyle of the humerus; from the radial collateral ligament of the elbow joint, and the anular ligament of the superior radio-ulnar joint; from the supinator crest of the ulna and from the posterior part of the triangular depression in front of it; and from a tendinous expansion which covers the surface of the muscle. The muscle is inserted into the lateral surface of the proximal one-third of the radius, reaching as low as the insertion of the Pronator teres. The insertion extends on to the anterior and posterior aspects of the radius, for the anterior and posterior borders of the bone incline medially at their upper ends (p. 376) (fig. 393).

Nerve-supply.—The Supinator is supplied by the posterior interosseous nerve (C. 5 and 6).

Actions.—The Supinator rotates the radius so as to turn the palm of the hand forwards.

The **Abductor pollicis longus** (figs. 605, 609, 610) lies distal to the Supinator and is closely related to the Extensor pollicis brevis. It arises from the lateral part of the posterior surface of the shaft of the ulna below the insertion of the Anconeus, from the interosseous membrane, and from the middle one-third of the posterior surface of the shaft of the radius immediately adjoining the insertion of the supinator. Passing obliquely downwards and laterally, it ends in a tendon (frequently two tendons), which runs in a groove on the lateral side of the lower end of the radius accompanied by the tendon of the Extensor pollicis brevis, is inserted into the radial side of the base of the first metacarpal bone and gives a slip to blend with the origin of the Abductor pollicis brevis. It occasionally gives a slip to the trapezium. Situated deeply above, it comes to the surface (fig. 609) at the junction of the lower fourth with the rest of the forearm, where it forms an oblique elevation, readily visible in the living subject.

Nerve-supply.—The Abductor pollicis longus is supplied by the posterior interosseous nerve (C. 7 and 8).

Actions.—The Abductor pollicis longus, acting with the Abductor pollicis brevis, abducts the thumb; acting with the Extensores pollicis, it extends the thumb at the carpometacarpal joint (p. 502).

The **Extensor pollicis brevis** (figs. 609, 610) lies on the medial side of, and is closely connected with, the Abductor pollicis longus. It arises from the posterior surface of the shaft of the radius below that muscle, and from the interosseous membrane. Its direction is similar to that of the Abductor pollicis longus, its tendon passing through the same groove on the lateral side of the lower end of the radius, to be inserted into the dorsal surface of the base of the proximal phalanx of the thumb.

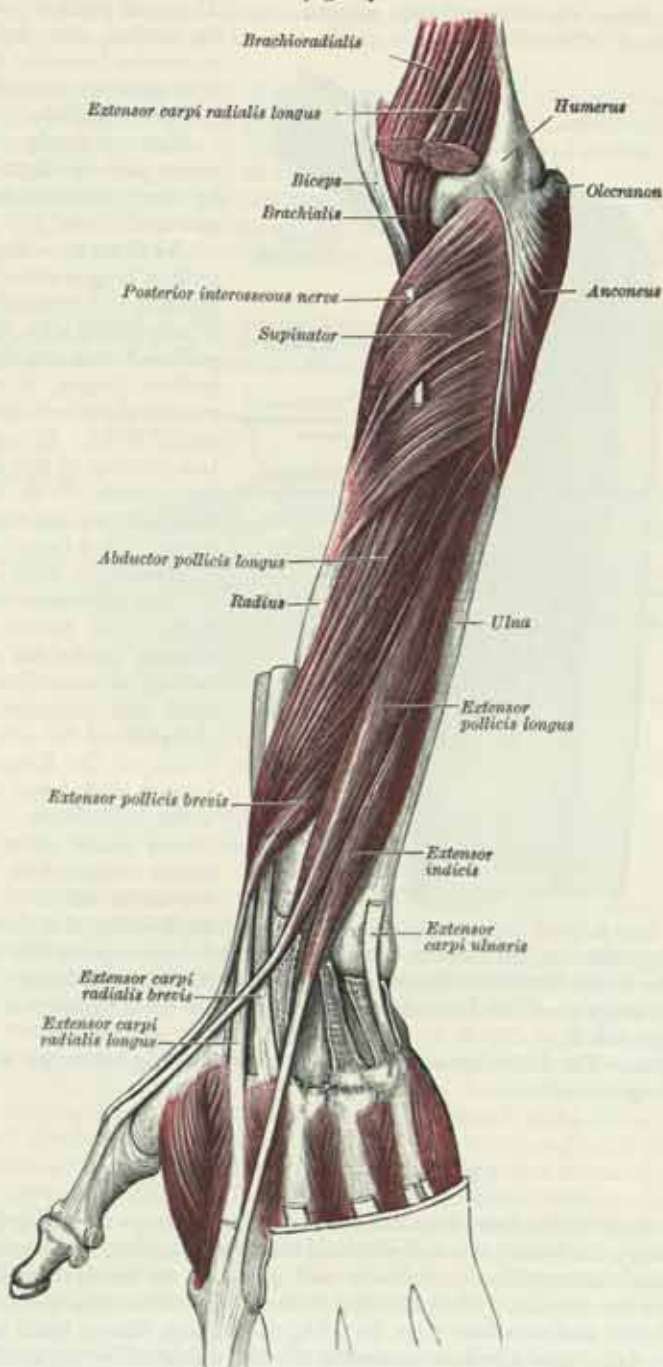
Nerve-supply.—The Extensor pollicis brevis is supplied by the posterior interosseous nerve (C. 7 and 8).

Actions.—The Extensor pollicis brevis extends the proximal phalanx of the thumb and, in continued action, helps to extend the metacarpal bone.

In the lower one-third of the forearm the Abductor pollicis longus and the Extensor pollicis brevis become superficial by emerging between the Extensor carpi radialis brevis and the Extensor digitorum. They then run obliquely across the tendons of the radial extensors of the wrist, cover the insertion of the Brachioradialis, and, passing through the most lateral compartment of the extensor retinaculum in a single synovial sheath, cross superficial to the styloid process of the radius and the radial artery.

The **Extensor pollicis longus** (figs. 609, 610) is larger than the **Extensor pollicis brevis**, the origin of which it partly covers. It arises from the lateral part of the middle one-third of the posterior surface of the shaft of the ulna below the origin

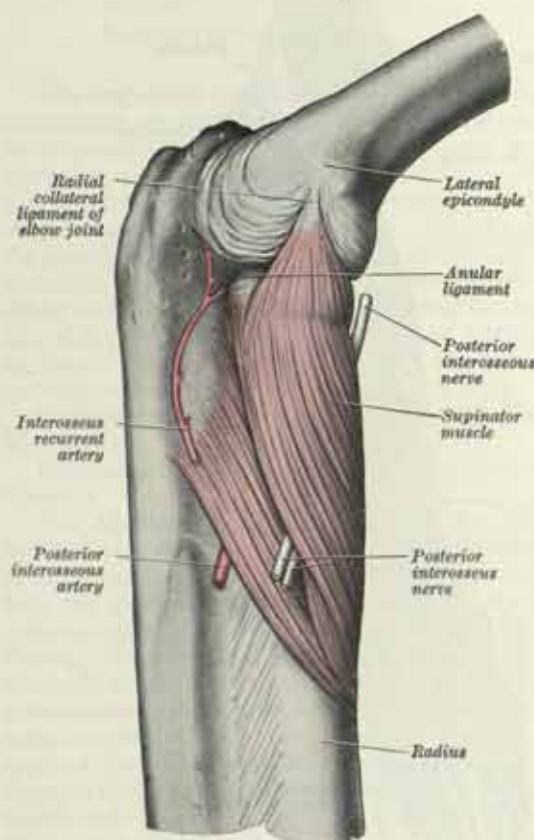
FIG. 610.—The left posterior antebrachial muscles.
Deep group.



of the **Abductor pollicis longus**, and from the interosseous membrane. It ends in a tendon, which passes through a separate compartment of the extensor retinaculum, lying in a narrow, oblique groove on the back of the lower end of the radius. It then crosses obliquely the tendons of the **Extensores carpi radiales longus et brevis**

(fig. 610), and is separated from the Extensor pollicis brevis by a triangular depression when the thumb is fully extended. This depression contains the radial artery and is often termed the 'anatomical snuff-box.' Finally, the tendon is inserted into the base of the distal phalanx of the thumb. As it lies on the dorsal surface of the proximal phalanx the tendon is joined on its lateral side by an expansion from

FIG. 611.—The right supinator muscle.
Postero-lateral aspect.



the tendon of insertion of the Abductor pollicis brevis and on its medial side by a similar expansion from the first Palmar interosseous muscle and the Adductor pollicis.

Nerve-supply.—The Extensor pollicis longus is supplied by the posterior interosseous nerve (C. 7 and 8).

Actions.—The Extensor pollicis longus extends the distal phalanx of the thumb and, acting in association with the Extensor pollicis brevis and the Abductor pollicis longus, it extends the proximal phalanx and the metacarpal bone. In continued action, owing to the obliquity of the course of its tendon, the Extensor pollicis longus adducts the extended thumb and rotates it laterally (p. 502).

The **Extensor indicis** (fig. 610) is a narrow, elongated muscle, medial to, and parallel with, the preceding. It arises from the posterior surface of the shaft of the ulna below the origin of the Extensor pollicis longus, and from the interosseous membrane. Its tendon passes under cover of the extensor retinaculum in the compartment which transmits the tendons of the Extensor digi-

torum; opposite the head of the second metacarpal bone it joins the ulnar side of the tendon of the Extensor digitorum which runs to the index finger.

Nerve-supply.—The Extensor indicis is supplied by the posterior interosseous nerve (C. 7 and 8).

Actions.—The Extensor indicis helps to extend the index finger and can assist in extending the wrist.

VI. THE MUSCLES OF THE HAND

The muscles of the hand are subdivided into three groups: 1, those of the thumb, which occupy the lateral side and produce the *thenar eminence*; 2, those of the little finger, which occupy the medial side and give rise to the *hypothener eminence*; 3, those in the middle of the palm and between the metacarpal bones.

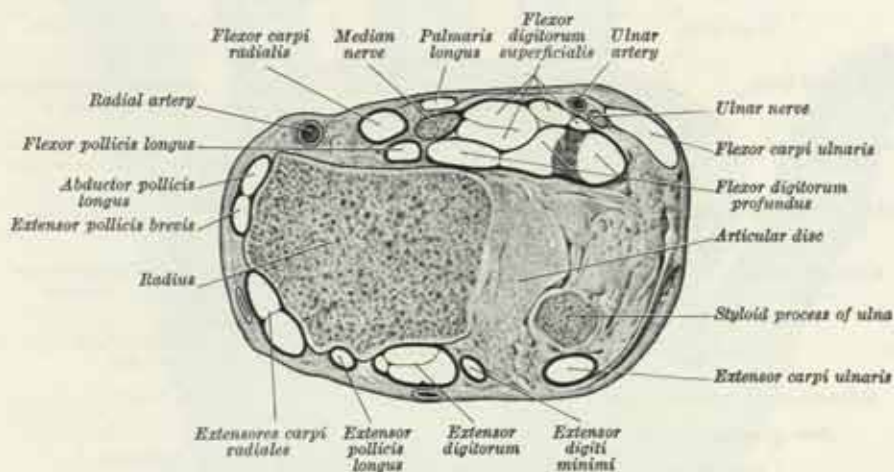
The **flexor retinaculum** (figs. 613, 614) is a strong, fibrous band which crosses the front of the carpus and converts the concavity formed by the anterior surfaces of the carpal bones into a tunnel, through which the flexor tendons of the digits and the median nerve pass. It is attached, medially, to the pisiform bone and to the hook of the hamate bone; laterally, it splits into two laminae, a superficial attached to the tubercles of the scaphoid and trapezium, and a deep, to the medial lip of the groove on the latter bone (fig. 613); with the groove on the trapezium the two

laminae form a tunnel, which is lined by a synovial sheath containing the tendon of the Flexor carpi radialis. The retinaculum is continuous, above, with the fascia covering the Flexor digitorum superficialis and also with the general investing layer of the antebrachial fascia. It is these two layers which separate on reaching the trapezium. The retinaculum is crossed superficially by the ulnar vessels and nerve, and the palmar cutaneous branches of the median and ulnar nerves. On its palmar surface the tendons of the Palmaris longus and Flexor carpi ulnaris are partly inserted; below, it gives origin to some of the short muscles of the thumb and little finger.

A localised thickening in the general investing layer of the antebrachial fascia which extends laterally from the pisiform bone is termed the *superficial part of the flexor retinaculum*. It crosses in front of the ulnar vessels and nerves and blends with the rest of the retinaculum on their lateral side.

The synovial sheaths of the tendons on the front of the wrist.—Two synovial sheaths envelop the flexor tendons as they traverse the carpal tunnel, one for the Flexores digitorum superficialis et profundus, the other for the Flexor pollicis longus

FIG. 612.—Transverse section, passing through the distal end of the right radius and the styloid process of the right ulna, made with the hand and forearm in full supination. Viewed from the distal aspect.

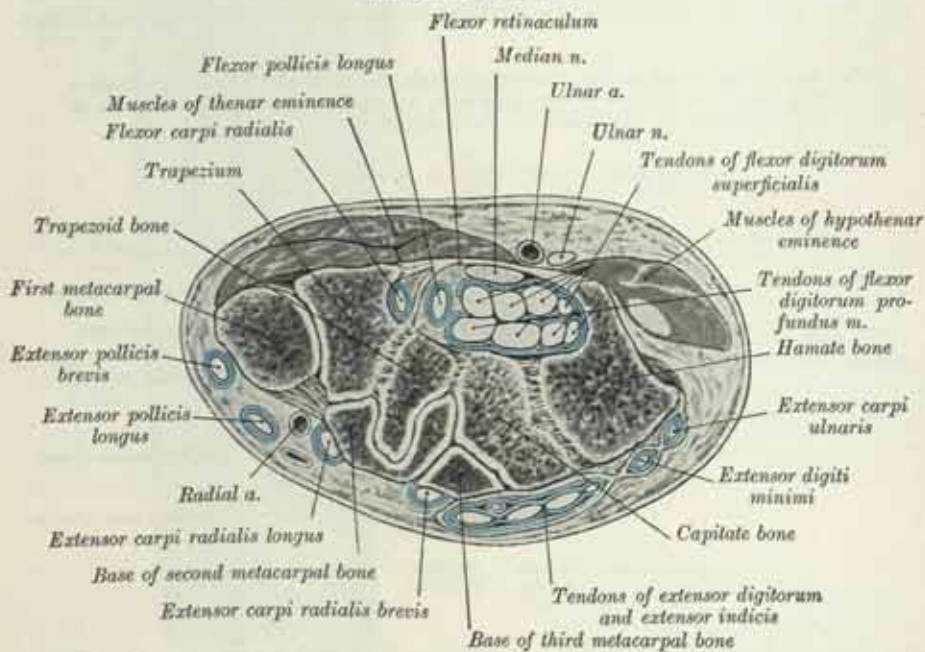


(fig. 613). These sheaths extend into the forearm for about 2.5 cm. above the flexor retinaculum, and occasionally communicate with each other behind that structure. The sheath of the Flexores digitorum tendons reaches about halfway along the metacarpal bones, where it ends in blind diverticula around the tendons to the index, middle, and ring fingers (fig. 614). It is prolonged on the tendons to the little finger and usually communicates with the digital synovial sheath of these tendons. A transverse section through the carpus (fig. 613) shows that the tendons have been invaginated into the sheath from the lateral side. The parietal layer lines the flexor retinaculum and the floor of the carpal tunnel and is reflected, at the lateral side, on to the tendons of the flexor digitorum superficialis from in front, and on to those of the flexor digitorum profundus from behind. On the medial side a recess of the sheath is insinuated between the two groups of tendons for a variable distance. The sheath of the tendon of the Flexor pollicis longus, which may be separate or may communicate with the common flexor sheath behind the flexor retinaculum, is continued along the thumb as far as the insertion of the tendon. The fibrous sheaths enveloping the terminal parts of the tendons of the Flexores digitorum have already been described (p. 630).

The **extensor retinaculum** (fig. 615) is a strong, fibrous band, extending obliquely across the back of the wrist, and consisting of part of the antebrachial fascia, strengthened by the addition of some obliquely transverse fibres. It is attached, medially, to the styloid process of the ulna and to the triquetral and pisiform bones; laterally, to the anterior border of the radius; and, in its passage across the wrist, to the ridges on the posterior surface of the radius.

The synovial sheaths of the tendons on the back of the wrist.—Deep to the extensor retinaculum there are six tunnels for the passage of the extensor tendons, each tunnel containing a synovial sheath. One is found in each of the following positions (fig. 615): (1) on the lateral side of the styloid process of the radius, for the tendons of the Abductor pollicis longus and Extensor pollicis brevis; (2) behind the styloid process, for the tendons of the Extensores carpi radiales longus et brevis; (3) on the medial side of the dorsal tubercle of the radius, for the tendon of the Extensor pollicis longus; (4) on the medial side of the latter, for the tendons of the Extensor digitorum and Extensor indicis; (5) opposite the interval between the radius and ulna, for the Extensor digiti minimi; (6) between the head and the styloid process of the ulna, for the tendon of the Extensor carpi ulnaris. The sheaths of the tendons of the Abductor pollicis longus, Extensores pollicis brevis et longus,

FIG. 613.—A transverse section through the left wrist, showing the tendons and their synovial sheaths.



The section is slightly oblique and divides the distal row of the carpus, and the bases of the first, second and third metacarpal bones. The arrangement of the tendons of the flexors of the fingers shown in the figure is not diagrammatic but represents the actual condition at this level. Observe that the carpometacarpal joint of the thumb is shut off from the joint between the trapezium and the base of the second metacarpal bone.

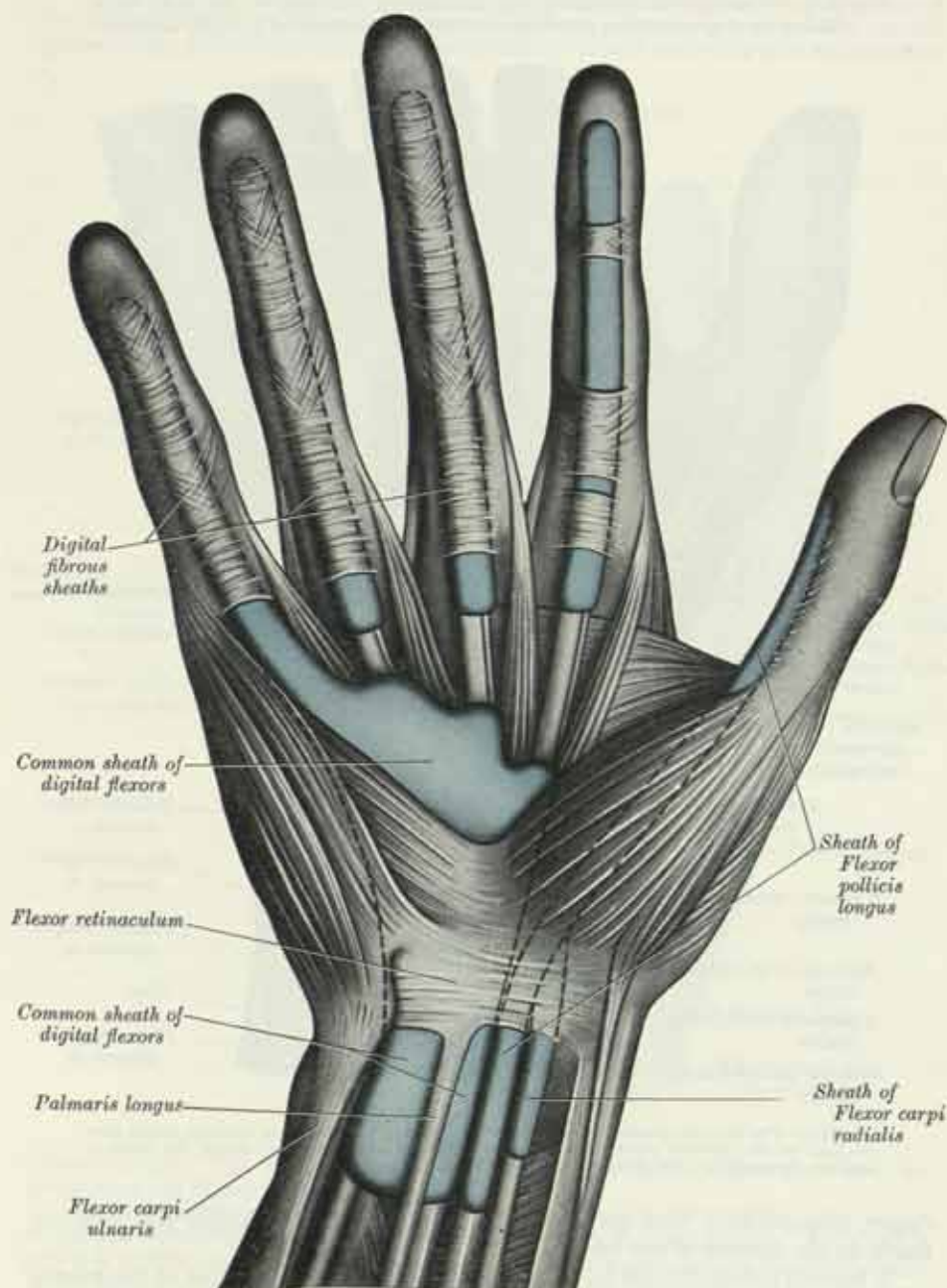
Extensores carpi radiales, and Extensor carpi ulnaris stop immediately proximal to the bases of the metacarpal bones, while those of the Extensor digitorum, Extensor indicis and Extensor digiti minimi are prolonged to the junction of the proximal with the intermediate one-third of the metacarpus.

The **palmar aponeurosis** (fig. 616) invests the muscles of the palm, and consists of central, lateral and medial portions.

The **central portion** occupies the middle of the palm, is triangular in shape, and of great strength and thickness. Its apex is continuous with the distal margin of the flexor retinaculum and gives insertion to the expanded tendon of the Palmaris longus muscle. Its base divides into four slips, one for each finger. The slips give off superficial fibres to the skin of the palm and fingers; those to the palm joining the skin at the furrow corresponding to the metacarpophalangeal joints, and those to the fingers passing into the skin at the transverse folds at the roots of the fingers. The deeper part of each slip subdivides into two processes which are continuous with the fibrous sheaths of the flexor tendons; from the sides of these processes offsets are attached to the deep transverse metacarpal ligaments. By this arrangement short

channels are formed on the front of the heads of the metacarpal bones; through these the flexor tendons pass. The intervals between the four slips transmit the digital vessels and nerves, and the tendons of the Lumbrical muscles. At the points

FIG. 614.—The synovial sheaths of the tendons on the front of the right wrist and hand. Diagrammatic. (After J. C. B. Grant.)



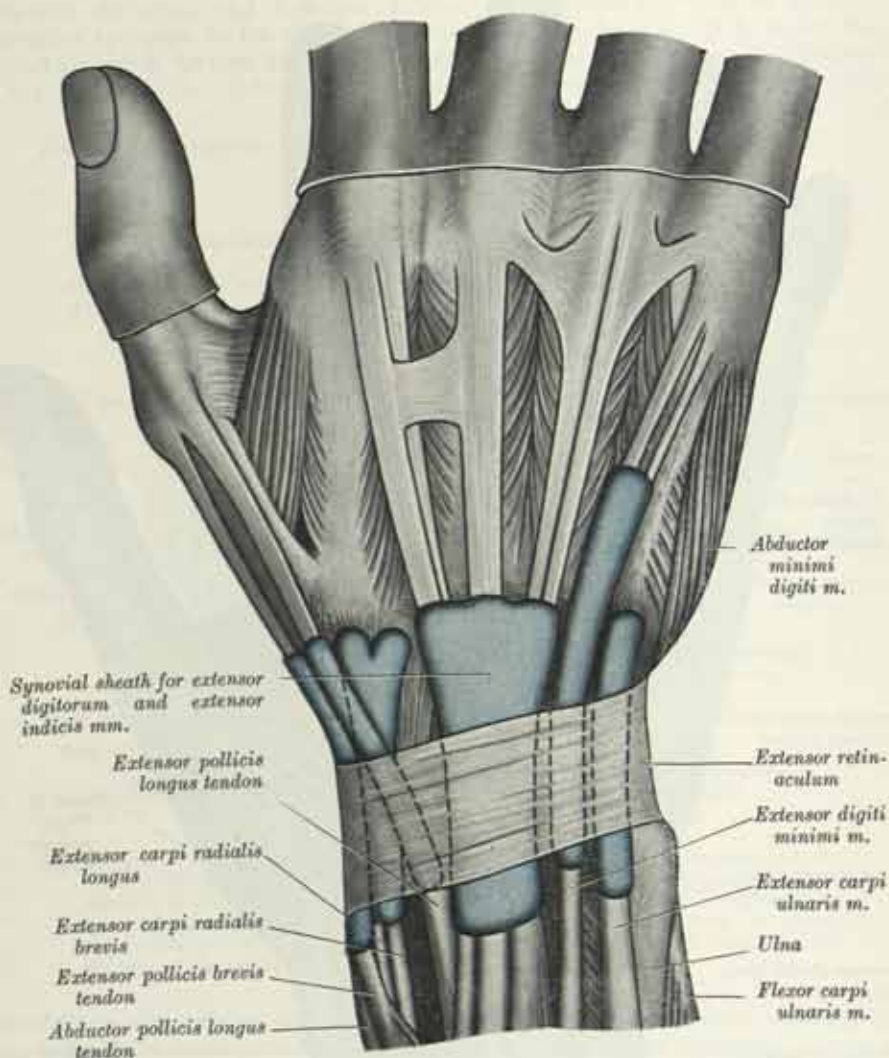
Note.—Where they are exposed, the synovial sheaths are shown in blue, but where they are hidden by overlying structures, their margins are indicated by interrupted black lines.

of division into the slips mentioned, numerous strong, transverse fibres bind the separate processes together. The central part of the palmar aponeurosis is intimately bound to the skin by dense fibro-areolar tissue, and the proximal part of its

medial margin gives origin to the *Palmaris brevis*. It covers the superficial palmar arch, the tendons of the *Flexores digitorum*, the terminal part of the median nerve, and the superficial part of the ulnar nerve.

The *lateral* and *medial portions* of the palmar aponeurosis are thin, fibrous layers which cover the muscles of the ball of the thumb and the short muscles of the little

FIG. 615.—The synovial sheaths of the tendons on the back of the right wrist.
(Based on a specimen prepared for the original drawing by J. C. B. Grant.)



Note.—The synovial sheaths are shown in *Nas*, but they have not been coloured where they lie deep to the extensor retinaculum. In this situation, and where one sheath lies deep to another, the margins of the sheaths are indicated by the broken lines.

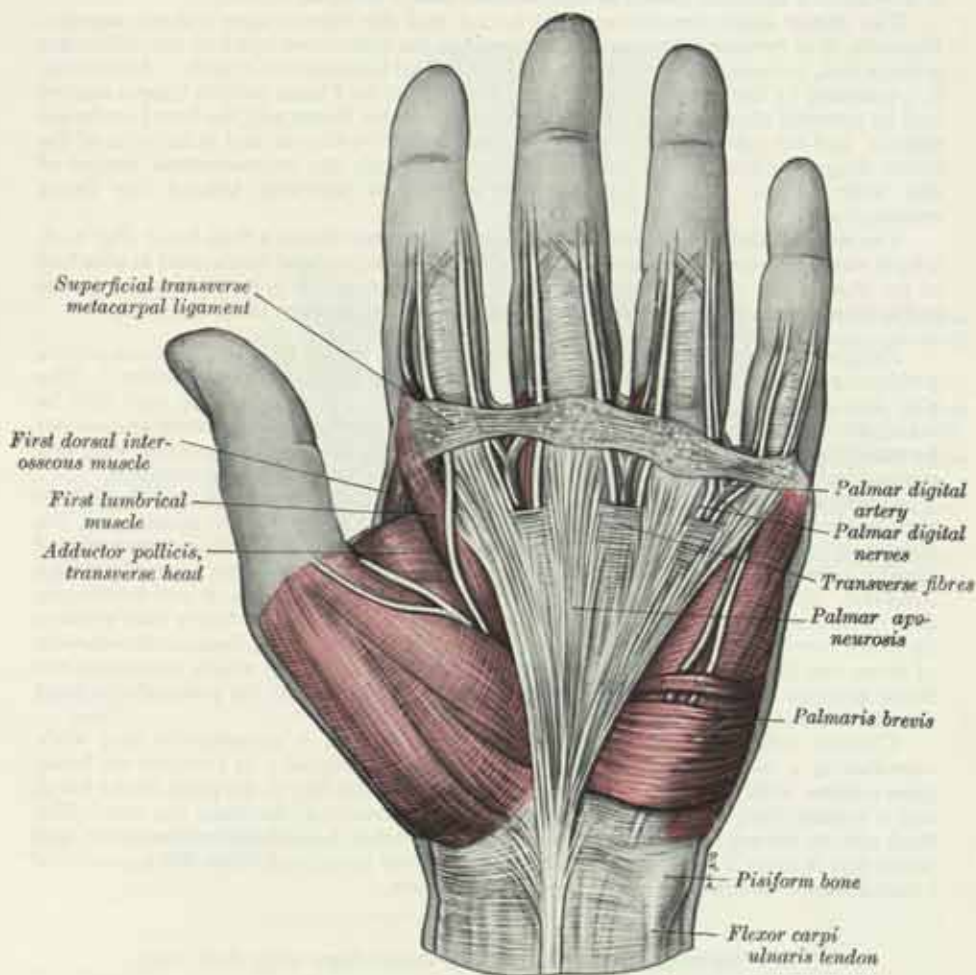
finger, respectively; they are continuous with the central portion and with the fascia on the dorsum of the hand.

A septum passes dorsally from each border of the central portion of the palmar aponeurosis. The *medial palmar septum* lies close to the lateral side of the *Opponens digiti minimi* and reaches the palmar surface of the fifth metacarpal bone. At its distal end it is continuous with the slip of the palmar aponeurosis to the medial side of the fibrous sheath of the little finger; at its proximal end it reaches the hook of the hamate bone and the pisohamate ligament and is pierced by the deep branches of the ulnar nerve and artery. The *lateral palmar septum* passes dorsally from the lateral border of the central portion of the palmar aponeurosis to reach the palmar

surface of the first metacarpal bone. It lies along the medial side of the *Flexor brevis* and *Opponens pollicis* muscles, intervening between them and the *Flexor pollicis longus* tendon and its synovial sheath. At its proximal end it reaches the tubercle of the trapezium and is pierced by the branch from the median nerve to the muscles of the thenar eminence.

The fascial spaces of the palm.—The central part of the palm, which lies behind the central portion of the palmar aponeurosis and between the lateral and medial palmar septa, is further subdivided into medial and lateral parts by a thin intermediate

FIG. 616.—The left palmar aponeurosis.



palmar septum. The medial area has been termed the *middle palmar space* and the lateral area the *thenar space*.

The *intermediate palmar septum* lies between the flexor tendons of the index finger on the lateral side and the second lumbrical muscle on the medial side. At its distal end it is continuous with the slip given by the palmar aponeurosis to the medial side of the fibrous sheath of the index and the adjoining deep transverse metacarpal ligament. Dorsally, it blends with the fasciæ covering the distal part of the second Palmar interosseous muscle and the transverse head of the *Adductor pollicis*, and it can be traced medially on the latter muscle to the third metacarpal bone. Anteriorly, it is attached to the deep surface of the palmar aponeurosis, but at its proximal end it meets the common flexor synovial sheath and blends with the connective tissue on its posterior surface. It should be stated unequivocally that, as an anatomical entity, the intermediate palmar septum is exceedingly disappointing. However, it would appear that when pus accumulates on either side of it, the adjoining areolar tissue is compressed

against it and helps it to form an effective septum, capable of determining the direction of spread.

The *middle palmar space* lies between the medial palmar septum and the intermediate septum. Its dorsal wall is formed by the third, fourth and fifth metacarpal bones, by the fascia covering the Interosseous muscles in the third and fourth spaces, and by the fascia covering the medial part of the transverse head of the Adductor pollicis. Its anterior wall is formed by the central portion of the palmar aponeurosis and, proximally, by the common flexor synovial sheath. The middle palmar space contains the flexor tendons of the fifth, fourth and third fingers, the fourth, third and second lumbrical muscles, the superficial palmar arch and the digital vessels and nerves for the fifth, fourth, third and ulnar side of the index finger. Distally, the space communicates with the subcutaneous tissues at the webs between the fingers: proximally, it may extend upwards dorsal to the common flexor synovial sheath.

The *thenar space* lies between the lateral and the intermediate palmar septum. Dorsally, it is bounded by the fascia covering the transverse head of the Adductor pollicis and, beyond its lower border, the first Dorsal interosseous muscle. Anteriorly, it is bounded by the palmar aponeurosis. It contains the Flexor pollicis longus tendon and its synovial sheath, the Flexor tendons of the index finger and the first Lumbrical muscle, and the palmar digital vessels and nerves of the thumb and radial side of the index finger. Distally the space communicates with the subcutaneous tissues of the web of the thumb; proximally it extends upwards behind the flexor retinaculum.

The **superficial transverse metacarpal ligament** forms a thin band (fig. 616) which stretches across the roots of the fingers in the superficial fascia, and is attached to the skin of the clefts, and medially to the fifth metacarpal bone, forming a sort of rudimentary web. The digital vessels and nerves pass deep to these fasciculi.

Applied Anatomy.—The palmar aponeurosis is liable to undergo contraction, producing a very inconvenient deformity known as 'Dupuytren's contraction.' The ring and little fingers are most frequently implicated, but the others may also be involved. The proximal and middle phalanges become progressively flexed and cannot be straightened; but the distal phalanx, which is thus brought into contact with and pressed against the palm of the hand, may eventually become hyperextended.

Owing to their constant exposure to injury and septic influences, the fingers are very liable to become the seat of serious inflammatory mischief. In some cases, the inflammation may involve the sheath or theca of the flexor tendons, and may spread rapidly upwards along it; but the extent will depend upon the particular digit involved. From the description of the flexor sheaths given above, it will be evident that inflammation of the synovial sheaths of the thumb and little finger may prove a far more formidable affection than that of the other three digits, because the sheaths of these two digits communicate with the large synovial sheath which surrounds the flexor tendons (p. 641) and the inflammation may extend into the palm of the hand and behind the flexor retinaculum into the forearm.

Chronic inflammation of the common flexor sheath is occasionally met with, constituting a condition known as *compound palmar ganglion*; it presents an hour-glass outline, with a swelling in front of the wrist and another in the palm of the hand, and a constriction, corresponding to the flexor retinaculum, between the two. The fluid can be forced from the one swelling to the other behind the retinaculum, and when this is done a creaking sensation is sometimes perceived, from the presence of 'melon-seed' bodies in the interior of the ganglion.

1. THE LATERAL MUSCLES OF THE PALM (figs. 617, 618, 619)

Abductor pollicis brevis.
Opponens pollicis.

Flexor pollicis brevis.
Adductor pollicis.

The **Abductor pollicis brevis** (fig. 619) is a thin, subcutaneous muscle which occupies the radial part of the thenar eminence; its chief origin is from the flexor retinaculum, but a few fibres spring from the tubercles of the scaphoid bone and trapezium and some arise from the tendon of the Abductor pollicis longus (p. 638). Its medial fibres are inserted by a thin, flat tendon into the radial side of the base of the proximal phalanx of the thumb; its lateral fibres join the dorsal digital expansion of the thumb.

Nerve-supply.—The Abductor pollicis brevis is supplied by the lateral terminal branch of the median nerve (C. 8 and T. 1).

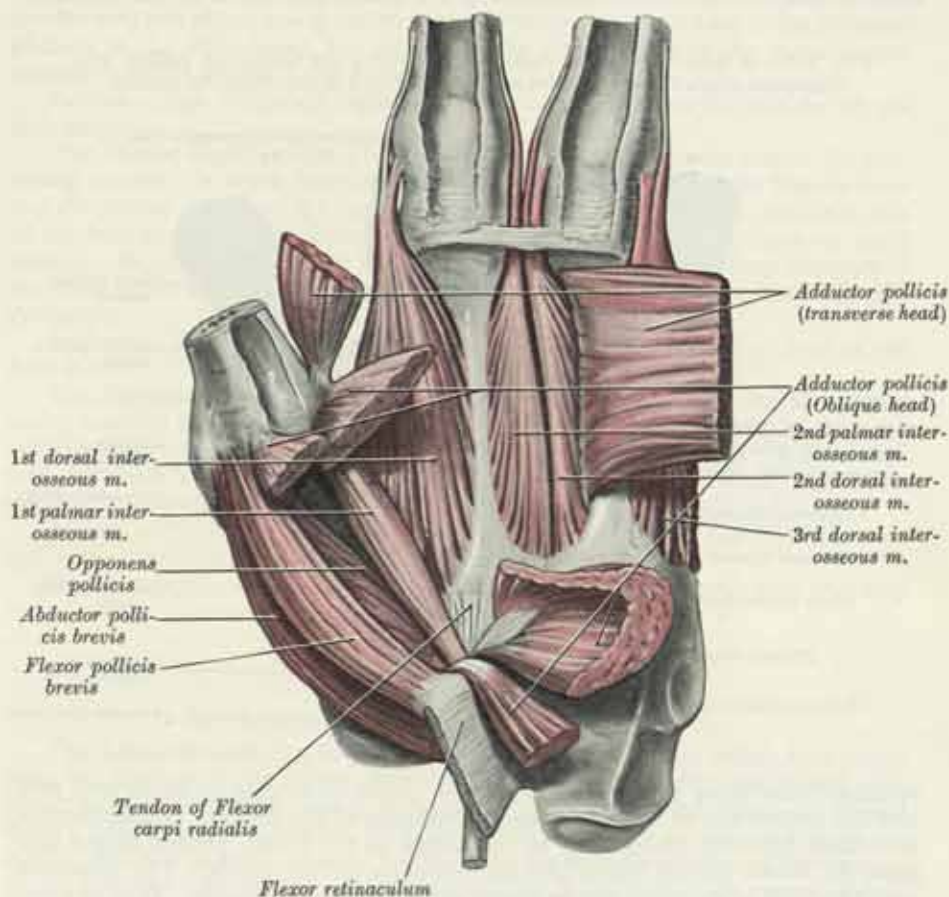
Actions.—The Abductor pollicis brevis draws the thumb forwards in a plane at right angles to the palm of the hand and rotates it medially. The movement

occurs primarily at the metacarpophalangeal joint and secondarily at the carpo-metacarpal joint, so that in full abduction of the thumb the digit is not in line with its metacarpal bone.

The **Opponens pollicis** (figs. 617, 618) is placed under cover of the Abductor pollicis brevis. It arises from the tubercle of the trapezium and from the flexor retinaculum, and is inserted into the whole length of the lateral border, and the lateral one-half of the palmar surface, of the metacarpal bone of the thumb.

Nerve-supply.—The Opponens pollicis is supplied by the lateral terminal branch of the median nerve (C. 8 and T. 1).

FIG. 617.—A dissection of the left hand to show the first palmar interosseous muscle (deep head of the Flexor pollicis brevis).



N.B.—The abductor and the flexor pollicis brevis have been displaced to the lateral side.

Actions.—The Opponens pollicis flexes the metacarpal bone of the thumb, i.e. bends it medially across the palm of the hand, and rotates it medially (p. 502). By this combination, which is termed opposition, the palmar surface of the tip of the thumb can be brought into contact with the palmar surface of the tip of any of the fingers, flexed at its metacarpophalangeal joint.

The **Flexor pollicis brevis** (fig. 619) lies on the ulnar side of the Abductor pollicis brevis. It arises from the lower border of the flexor retinaculum and the lower part of the tubercle of the trapezium; it passes along the radial side of the tendon of the Flexor pollicis longus, and is inserted into the radial side of the base of the proximal phalanx of the thumb; in its tendon of insertion there is a sesamoid bone. It is frequently more or less blended with the medial border of the opponens pollicis.

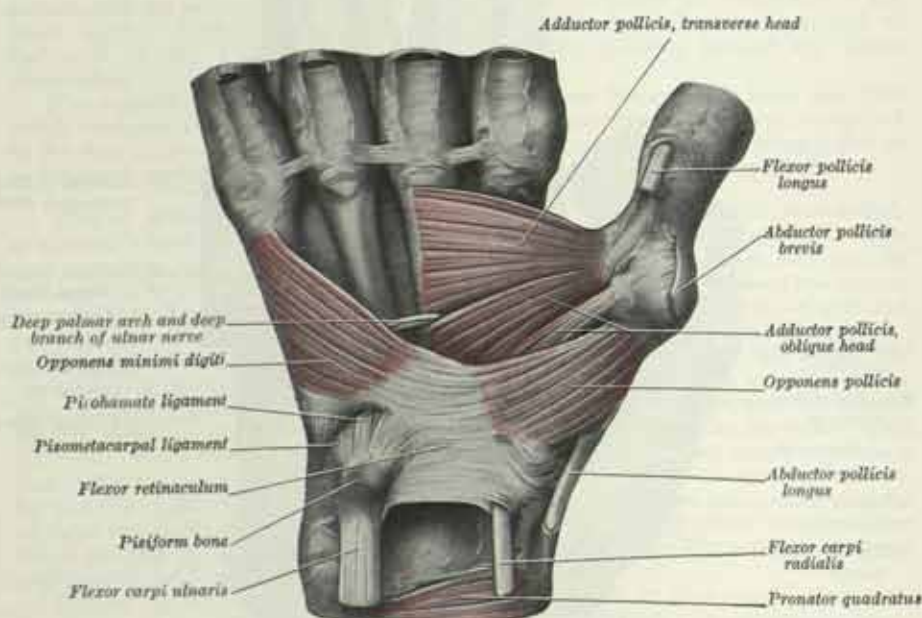
Nerve-supply.—The Flexor pollicis brevis usually receives a double nerve-

supply,* one from the lateral terminal branch of the median nerve (C. 8 and T. 1) and the other from the deep branch of the ulnar nerve. Not infrequently it is supplied by the median nerve only, and in a few cases its sole supply is derived from the deep branch of the ulnar nerve.

Actions.—The Flexor pollicis brevis flexes the proximal phalanx of the thumb and, continuing to act, it flexes the metacarpal bone and rotates it medially (p. 502). In the latter movement it co-operates with the Opponens pollicis muscle.

The **Adductor pollicis** (fig. 618) arises by two heads, an oblique and a transverse. The *oblique head* arises from the capitate and trapezoid bones, the bases of the second and third metacarpal bones, the palmar ligaments of the carpus and the sheath of the tendon of the Flexor carpi radialis. Most of its fibres converge to a tendon, which, uniting with the tendon of the transverse head of the Adductor, is inserted into the ulnar side of the base of the proximal phalanx of the thumb, a

FIG. 618.—A dissection of the right palm, showing the Opponens pollicis and Opponens digiti minimi muscles and the two heads of the Adductor pollicis.



sesamoid bone being present in the tendon. Some of its deepest fibres may pass into the medial side of the dorsal digital expansion of the thumb. A considerable fasciculus, however, passes deep to the tendon of the Flexor pollicis longus and joins the Flexor pollicis brevis and the Abductor pollicis brevis. The *transverse head* (fig. 618) is the most deeply seated of this group of muscles. It is of a triangular form, and arises from the distal two-thirds of the palmar surface of the third metacarpal bone; the fibres converge to be inserted, with the oblique head of the muscle and with the first palmar interosseous muscle, into the ulnar side of the base of the proximal phalanx of the thumb.

Nerve-supply.—The Adductor pollicis is supplied by the deep branch of the ulnar nerve (C. 8 and T. 1).

Action.—The Adductor pollicis approximates the thumb to the palm of the hand and it acts to greatest advantage when the abducted and flexed thumb is opposed to the fingers in gripping.

2. THE MEDIAL MUSCLES OF THE PALM (figs. 616, 618, 619)

Palmaris brevis.

Abductor digiti minimi.

Flexor digiti minimi brevis.

Opponens digiti minimi.

The **Palmaris brevis** (fig. 616) is a thin, quadrilateral muscle, placed beneath the skin of the ulnar side of the hand. It arises from the flexor retinaculum and from the medial border of the central part of the palmar aponeurosis; it is inserted into the skin on the ulnar border of the hand. It covers the ulnar artery and the superficial terminal branch of the ulnar nerve.

Nerve-supply.—The *Palmaris brevis* is supplied by the superficial branch of the ulnar nerve.

Action.—The *Palmaris brevis* wrinkles the skin on the ulnar side of the palm of the hand and deepens the hollow of the palm by accentuating the prominence of the hypothenar eminence. In this way it contributes to the security of the palmar grip.

The **Abductor digiti minimi** (fig. 619) is situated on the ulnar border of the palm of the hand. It arises from the pisiform bone, from the tendon of the *Flexor carpi ulnaris* and from the pisohamate ligament. It ends in a flat tendon which divides into two slips; one is inserted into the ulnar side of the base of the proximal phalanx of the little finger, the other into the ulnar border of the dorsal digital expansion of the *Extensor digiti minimi*.

Action.—The *Abductor digiti minimi* abducts the proximal phalanx of the little finger.

The **Flexor digiti minimi brevis** (fig. 619) lies on the radial side of the preceding muscle. It arises from the convex surface of the hook of the hamate bone and the palmar surface of the flexor retinaculum, and is inserted into the ulnar side of the base of the proximal phalanx of the little finger with the *Abductor digiti minimi*. Its origin is separated from that of the *Abductor* by the deep branches of the ulnar artery and nerve. This muscle may be wanting, or may be fused with the *Abductor*.

Actions.—The *Flexor digiti minimi brevis* flexes the proximal phalanx of the little finger.

The **Opponens digiti minimi** (fig. 618) is of a triangular form, and placed under cover of the *Flexor* and *Abductor*. It arises from the convexity of the hook of the hamate bone, and contiguous portion of the flexor retinaculum; it is inserted into the whole length of the ulnar margin of the fifth metacarpal bone. It is often divided into two lamellae by the deep branches of the ulnar artery and nerve.

Action.—The *Opponens digiti minimi* draws the fifth metacarpal bone forwards and rotates it laterally, so as to deepen the hollow of the palm.

Nerve-supply.—All the muscles of the little finger are supplied by the deep branch of the ulnar nerve (C. 8 and T. 1).

3. THE INTERMEDIATE MUSCLES

Lumbricales.

Interossei.

The **Lumbricales** (fig. 619) are four small fleshy fasciculi which take origin from the tendons of the *Flexor digitorum profundus*. The first and second arise from the radial sides and palmar surfaces of the tendons of the index and middle fingers respectively; the third, from the contiguous sides of the tendons of the middle and ring fingers; and the fourth, from the contiguous sides of the tendons of the ring and little fingers. Each passes to the radial side of the corresponding finger, and is inserted partly into the base of the proximal phalanx, but mainly into the lateral margin of the dorsal digital expansion of the *Extensor digitorum* covering the dorsal surface of the finger (figs. 607, 608).

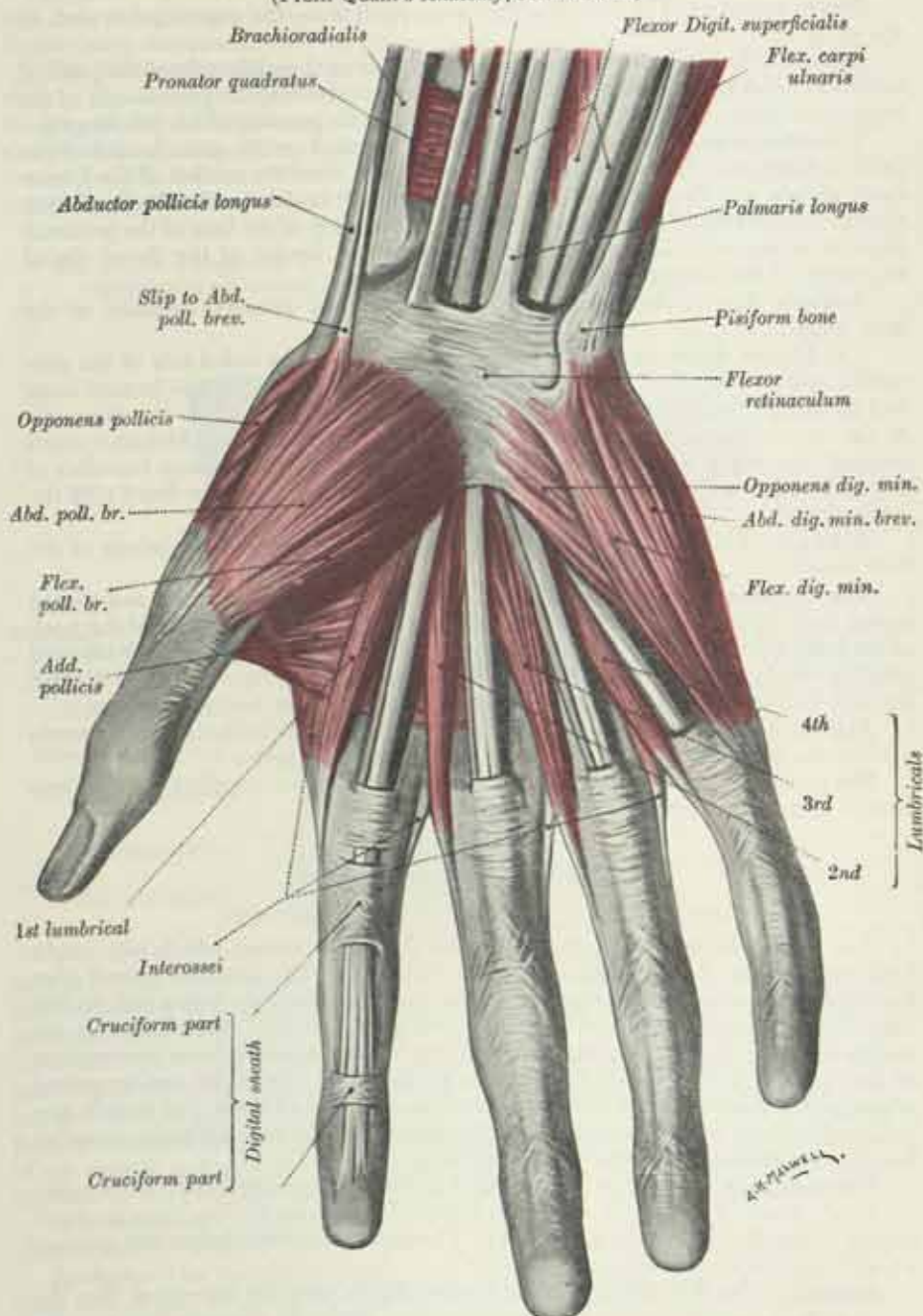
Nerve-supply.—The first and second Lumbricales are supplied by the median nerve (C. 8 and T. 1); the third and fourth Lumbricales by the deep terminal branch of the ulnar nerve (C. 8 and T. 1). The third Lumbrical frequently receives a twig from the median nerve.

Actions.—The Lumbricales, acting in association with the interossei, flex the digits at the metacarpophalangeal joints (*see also* p. 635). In doing so they exercise traction on the tendons of the *flexor digitorum profundus*. In certain circumstances the Lumbricales alone can extend the interphalangeal joints.

It may be noted that when the middle, ring or little finger is flexed fully at the metacarpophalangeal and the proximal interphalangeal joints, its distal phalanx can neither be flexed nor extended by voluntary effort so long as the other fingers are kept extended. The inability to extend the distal phalanx under these conditions is due to the fact that, owing to the way in which the *extensor digitorum* tendons are

inserted, the terminal phalanx can be extended only when the middle phalanx also is extended. The inability to flex the distal phalanx is probably due to the fact that,

FIG. 619.—Superficial dissection of muscles of the palm of the hand.
(From Quain's *Anatomy*, XI. Edition.)



with the exception of the tendon for the index finger, the tendons of the Flexor digitorum profundus do not become free until they reach the hand (p. 630), so that it is not until the other fingers are flexed that the phalanx concerned can be brought under control.

The *Interossei* occupy the intervals between the metacarpal bones, and are divided into a dorsal and a palmar set.

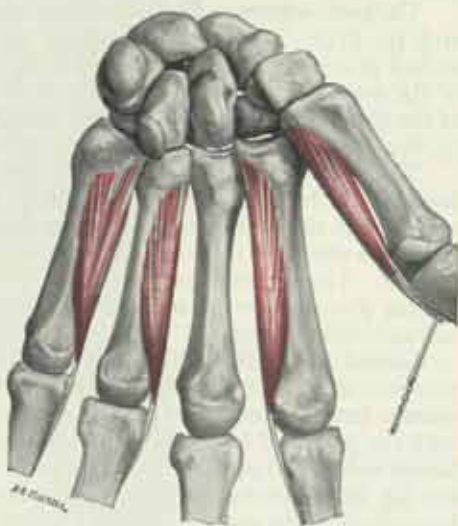
The **Interossei dorsales** (fig. 620), four in number, are bipennate muscles, each arising by two heads from the adjacent sides of the metacarpal bones, but more extensively from the metacarpal bone of the finger into which the muscle is inserted. They are inserted into the bases of the proximal phalanges and into the dorsal digital expansions (p. 634). Between the double origin of each of these muscles there is a narrow triangular interval; through the first of these intervals the radial artery passes; through each of the others a perforating branch from the deep palmar arch is transmitted. The *first*, and largest, is sometimes named the *Abductor indicis*; it is inserted *wholly** into the radial side of the proximal phalanx of the index finger. The *second* and *third* are inserted into the middle finger, the former into its radial, the latter into its ulnar side. Whereas the second is generally inserted into the digital expansion and into the proximal phalanx, the third is usually inserted into the digital expansion only (fig. 606). The *fourth*, too, may be wholly inserted into the digital expansion but it often sends an additional slip to the proximal phalanx.

The **Interossei palmares** (fig. 621), four in number, are smaller than the Dorsal interossei, and are placed upon the palmar surfaces of the metacarpal bones, rather than between them. With the exception of the first, each arises from the entire length of the metacarpal bone of one finger, and is inserted into the appropriate side of the dorsal digital expansion.

FIG. 620.—The Dorsal interosseous muscles of the left hand. Viewed from in front.



FIG. 621.—The Palmar interosseous muscles of the left hand. Viewed from in front.



The *first* (formerly known as the 'deep head of the Flexor pollicis brevis') arises from the ulnar side of the palmar surface of the base of the first metacarpal bone and is inserted, in common with a part of the oblique head of the Adductor pollicis.† It lies in front of the lateral head of the first Dorsal interosseous muscle, and is covered by the oblique head of the Adductor pollicis (fig. 617). The *second* arises from the ulnar side of the second metacarpal bone, and is inserted into the same side of the digital expansion of the index finger. The *third* arises from the radial side of the fourth metacarpal bone, and is inserted in common with the third Lumbrical (figs. 607, 608). The *fourth* arises from the radial side of the fifth metacarpal bone, and is inserted in common with the fourth Lumbrical. The attachment of these muscles to the base of each dorsal digital expansion (fig. 607) ensures the stability of the extensor tendon on the convexity of the head of the corresponding metacarpal bone during the movements of flexion and extension at the metacarpophalangeal joint.

* C. R. Salsbury, *J. Anat.*, Lond., 71, 1937.

† J. R. Napier, *J. Anat.*, Lond., 86, 1952.

Nerve-supply.—Both Dorsal and Palmar interossei are supplied by the deep branch of the ulnar nerve (C. 8 and T. 1).

Actions.—The Dorsal interossei abduct the fingers from an imaginary line drawn longitudinally through the centre of the middle finger; and the Palmar interossei adduct the fingers to that line (*see also* p. 505). The Interossei, in conjunction with the Lumbricals, flex the proximal phalanges; in consequence of their insertions into dorsal digital expansions they are able, under certain conditions (p. 635), to extend the middle and distal phalanges. The first Palmar interosseous flexes and adducts the proximal phalanx of the thumb.

Clinical observations indicate that all the small muscles of the hand receive their motor innervation from T. 1.

THE FASCIÆ AND MUSCLES OF THE LOWER LIMB

The muscles of the lower limb are subdivided into groups corresponding with the different regions of the limb.

- | | |
|---------------------------------|--------------------------|
| I. Muscles of the iliac region. | III. Muscles of the leg. |
| II. Muscles of the thigh. | IV. Muscles of the foot. |

I. THE MUSCLES OF THE ILIAC REGION (fig. 622)

- | | | |
|--------------|--------------|----------|
| Psoas major. | Psoas minor. | Iliacus. |
|--------------|--------------|----------|

The **fascia iliaca** covers the Psoas and Iliacus. It is thin above, but becomes gradually thicker as it approaches the inguinal ligament.

The *portion covering the Psoas* is thickened above to form the medial lumbocostal arch (p. 585). Medially, the fascia covering the Psoas is attached by a series of arched processes to the intervertebral discs, and prominent margins of the bodies of the vertebræ, and to the upper part of the sacrum. Laterally, above the crest of the ilium, it blends with the fascia covering the front of the Quadratus lumborum (p. 602), below the crest, with the fascia covering the Iliacus.

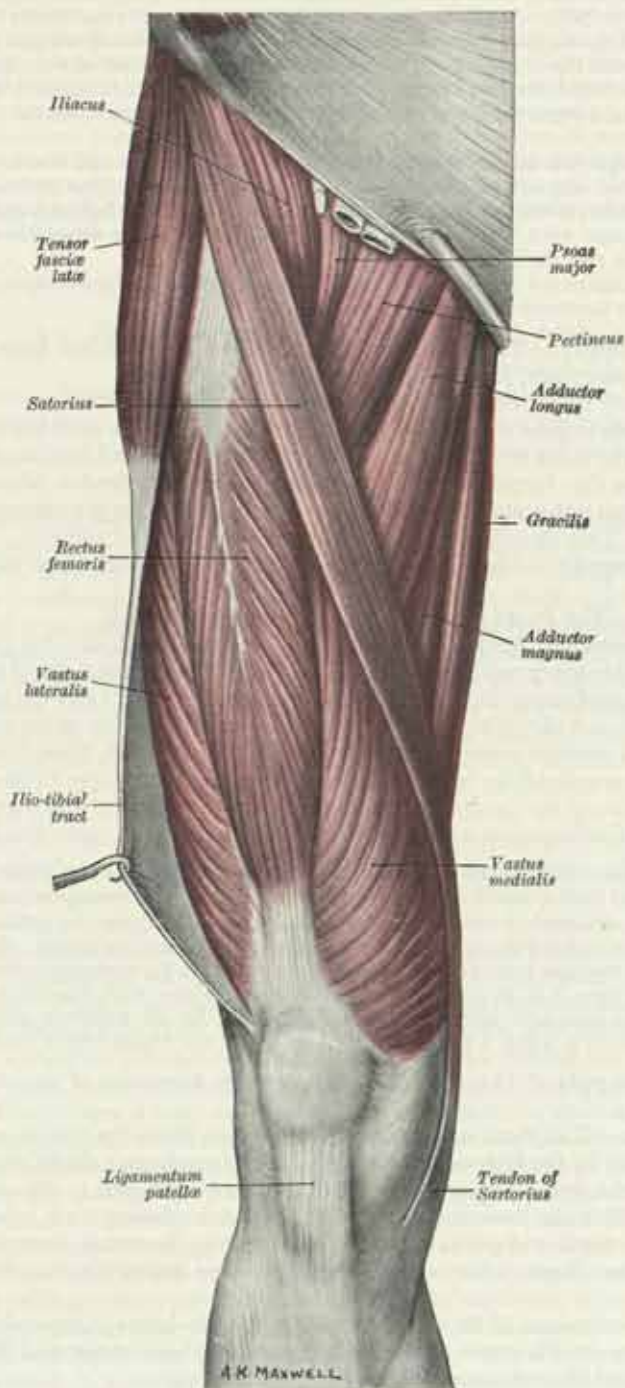
The *portion covering the Iliacus* is connected, laterally, to the whole length of the inner lip of the iliac crest, and medially, to the brim of the true pelvis, where it blends with the periosteum. It is attached to the iliopectineal eminence and there receives a slip from the tendon of insertion of the Psoas minor, when that muscle is present. The external iliac vessels lie in front of the fascia but the branches of the lumbar plexus of nerves are behind it; it is separated from the peritoneum by the extraperitoneal tissue.

Lateral to the femoral vessels, the iliac fascia is intimately connected to the posterior margin of the inguinal ligament, and is there continuous with the transversalis fascia. Medially it passes behind the femoral vessels to become continuous with the pectineal fascia and attached to the pecten pubis. At the junction of its lateral and medial parts it is attached to the iliopectineal eminence and the capsule of the hip joint. It thus forms a septum between the inguinal ligament and the hip bone dividing the space here into a lateral part, the *lacuna musculorum*, containing the Psoas major, the Iliacus and the femoral nerve, and a medial part, the *lacuna vasorum*, transmitting the femoral vessels. The downward continuation of the fascia covering the Iliacus muscle forms the posterior wall of the femoral sheath (p. 600).

The **Psoas major** (fig. 622) is a long fusiform muscle placed on the side of the lumbar region of the vertebral column and the brim of the true pelvis. It arises (1) from the anterior surfaces and lower borders of the transverse processes of all the lumbar vertebræ; (2) by five slips or digitations, each of which takes origin from the bodies of two vertebræ and their intervertebral disc; the highest slip arises from the lower margin of the body of the twelfth thoracic vertebra, the upper margin of the body of the first lumbar vertebra and the interposed disc, the lowest slip from the adjacent margins of the bodies of the fourth and fifth lumbar vertebræ and the interposed disc; (3) from a series of tendinous arches extending across the constricted parts of the bodies of the lumbar vertebræ between the preceding slips; the lumbar arteries and veins, and filaments from the sympathetic trunk, pass deep to these arches. The muscle proceeds downwards along the brim of the true pelvis, passes behind the inguinal ligament and in front of the capsule of the hip joint, and ends in a tendon which receives, on its lateral side, nearly the whole of the fibres of the Iliacus, and is inserted into the lesser trochanter of the femur. A large bursa,

which occasionally communicates with the cavity of the hip joint, separates the tendon from the pubis and the capsule of the joint.

FIG. 622.—Muscles on the front of the thigh, superficial dissection.
(From Quain's *Anatomy*, XI. Edition.)



Relations.—The uppermost part of the Psoas major lies behind the diaphragm and occupies the lowest part of the posterior mediastinum. It may be in contact with the posterior, lower limit of the pleural sac. In the abdomen the Psoas major is in relation by its *anterolateral surface* with the medial lumbocostal arch, the fascia covering

the muscle, the extraperitoneal tissue and peritoneum, the kidney, Psoas minor, renal vessels, ureter, testicular (or ovarian) vessels, and genitofemoral nerve. In front the right Psoas is overlapped by the inferior vena cava and crossed by the terminal portion of the ileum, and the left is crossed by the colon. Its *posterior surface* is in relation with the transverse processes of the lumbar vertebrae, and the medial edge of the Quadratus lumborum. The lumbar plexus is situated in the posterior part of the substance of the muscle. *Medially*, the muscle is in relation with the bodies of the lumbar vertebrae and the lumbar vessels. Along its anterior (or medial) margin the muscle is in relation with the sympathetic trunk, and the aortic lymph glands and, along the brim of the pelvis, with the external iliac artery. This margin is covered by the inferior vena cava on the right side, and on the left side lies posterior and lateral to the abdominal aorta.

In the thigh it is in relation, *in front*, with the fascia lata and the femoral artery; *behind*, with the capsule of the hip joint, from which it is separated by a bursa; by its *medial border*, with the Pectineus and medial circumflex femoral artery, and also with the femoral vein, which may overlap it slightly; by its *lateral border*, with the femoral nerve and the Iliacus.

The femoral nerve descends at first through the fibres of Psoas major, and then lies in the furrow between it and the Iliacus.

Nerve-supply.—The Psoas major is supplied by branches from the second, third and, sometimes, fourth lumbar nerves.

Actions.—The Psoas major acts conjointly with the Iliacus.

The **Psoas minor** is placed in front of the Psoas major within the abdomen. It arises from the sides of the bodies of the twelfth thoracic and first lumbar vertebrae and from the disc between them. It ends in a long, flat tendon which is inserted into the pecten pubis and iliopectineal eminence, and, by its lateral border, into the iliac fascia. This muscle is absent in about 40 per cent. of subjects.

Nerve-supply.—The Psoas minor is supplied by a branch from the first lumbar nerve.

Action.—The Psoas minor is a weak flexor of the trunk.

The **Iliacus** (fig. 622) is a flat, triangular muscle which fills the iliac fossa. It arises from the upper two-thirds of the iliac fossa, from the inner lip of the iliac crest, from the ventral sacro-iliac and ilio-lumbar ligaments, and from the upper surface of the lateral part of the sacrum (fig. 262); in front, it reaches as far as the anterior superior and anterior inferior iliac spines, and receives a few fibres from the upper part of the capsule of the hip joint. Most of its fibres converge to be inserted into the lateral side of the tendon of the Psoas major, but some of them are attached to the shaft of the femur for 2.5 cm. below and in front of the lesser trochanter.

Relations.—Within the abdomen, the Iliacus is in relation, by its *anterior surface*, with the iliac fascia, which separates the muscle from the extraperitoneal tissue and peritoneum, and with the lateral femoral cutaneous nerve; on the right side, with the caecum; on the left side, with the iliac part of the descending colon; by its *posterior surface*, with the iliac fossa; by its *medial border*, with the Psoas major and femoral nerve.

In the thigh, it is in relation, by its *anterior surface*, with the fascia lata, Rectus femoris, Sartorius and arteria profunda femoris; by its *posterior surface*, with the capsule of the hip joint, a bursa common to it and the Psoas major being interposed.

Nerve-supply.—The Iliacus is supplied by branches of the femoral nerve (L. 2 and 3).

Actions.—The Psoas major, acting from above, flexes the thigh upon the pelvis, being assisted by the Iliacus: at the same time it produces a slight degree of medial rotation of the femur owing to the relation of its line of pull to the axis of rotation (p. 515). When the Psoas major and Iliacus of both sides act from below, they serve to bend the trunk and pelvis forwards, as in raising the trunk from the recumbent posture. One Psoas major, acting alone, produces lateral flexion of the vertebral column.

The maintenance of the erect attitude at the hip joints is dependent on perfect balance between the tonus of the Rectus femoris, Psoas major and Iliacus, on the one hand, and the extensors of the joints, on the other.

It seems not improbable that the Iliacus functions mainly as a postural muscle.

Applied Anatomy.—When an abscess forms beneath the fascia covering the Psoas and Iliacus, as often happens, the pus is formed in an osseofibrous space which is closed on all sides within the abdomen, and is open only at its lower part, where the fascia is prolonged over the muscles into the thigh. When the disease is in the thoracic

vertebræ, the pus tracks down the posterior mediastinum in front of the bodies of the vertebræ, and, passing behind the medial lumbocostal arch, enters the sheath of the Psoas, down which it travels as far as the pelvic brim; it then passes deep to the iliac portion of the fascia, and fills up the iliac fossa. In consequence of the attachment of the fascia to the arcuate line, it rarely finds its way into the true pelvis, but passes behind the inguinal ligament into the thigh, lateral to the femoral vessels. When the lumbar vertebræ are the seat of the disease, the pus finds its way directly into the substance of the Psoas. The muscular fibres are destroyed, and the nerves contained in the abscess are isolated and exposed in its interior; the iliac vessels, which lie in front of the fascia, remain intact, and the peritoneum seldom becomes implicated. All psoas abscesses do not, however, pursue this course; the pus may leave the sheath of the muscle above the crest of the ilium, and tracking backwards may point in the loin (*lumbar abscess*); or it may point above the inguinal ligament in the inguinal region; or it may follow the course of the branches of the internal iliac vessels into the true pelvis, and, passing through the greater sciatic foramen into the gluteal region, may discharge itself on the back of the thigh.

II. THE MUSCLES OF THE THIGH

1. THE ANTERIOR FEMORAL MUSCLES (fig. 622)

Tensor fasciæ latæ.
Sartorius.

Quadriceps femoris { Rectus femoris.
Vastus lateralis.
Vastus medialis.
Vastus intermedius.

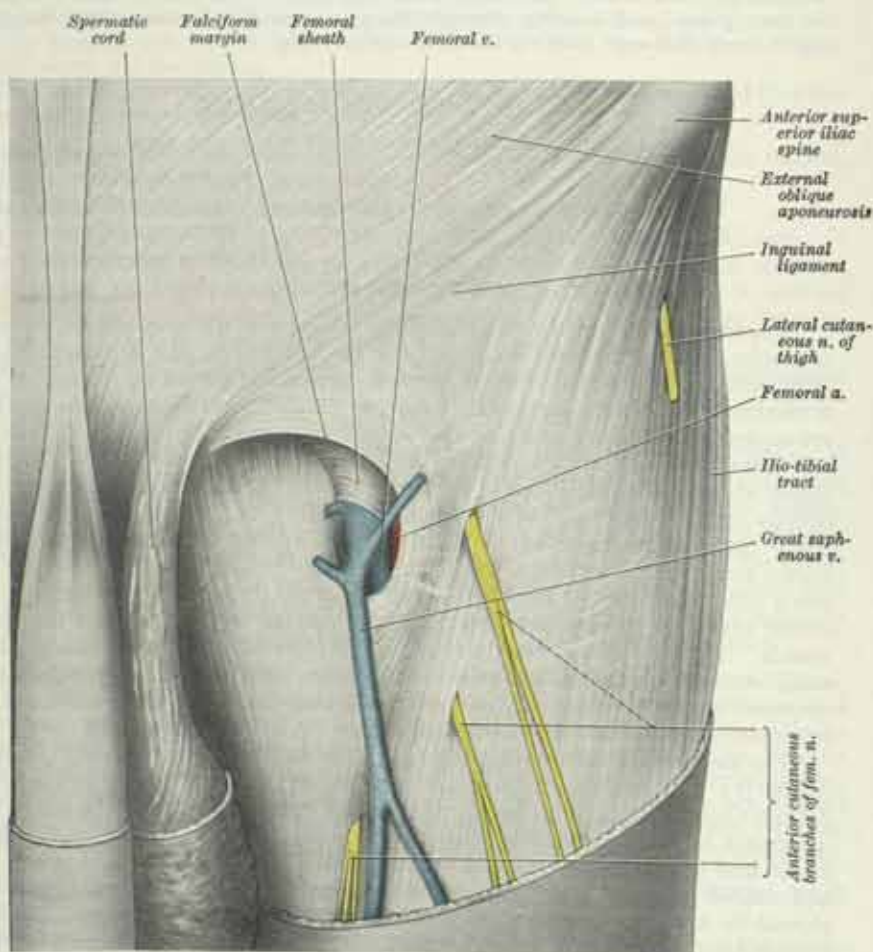
Articularis genu.

The **superficial fascia** forms a continuous layer over the whole thigh; it consists of areolar tissue containing much fat in its meshes, and may be separated into two or more layers, between which the superficial vessels and nerves are found. It varies in thickness in different parts of the limb; in the groin it is thick, and the two layers are separated from each other by the superficial inguinal lymph glands, the great saphenous vein and several smaller vessels. The superficial layer is continuous above with the superficial fascia of the abdomen. The deep layer is a very thin, fibrous stratum, best marked on the medial side of the great saphenous vein and below the inguinal ligament. It is placed behind the subcutaneous vessels and nerves and upon the surface of the fascia lata. It is intimately adherent to the fascia lata a little below the inguinal ligament. It covers the saphenous opening, being closely united to its circumference, and is connected to the sheath of the femoral vessels. The portion covering the opening is perforated by the great saphenous vein, small blood vessels and lymph vessels, hence it has been termed the *cribriform fascia*, the openings for these vessels having been likened to the holes in a sieve. A large subcutaneous bursa is found in the superficial fascia over the patella.

The **deep fascia** of the thigh is named, from its great extent, the *fascia lata* (fig. 623); it invests the whole of this region of the limb, but varies in thickness in different parts. Thus, it is thicker in the upper and lateral parts of the thigh, where it receives a fibrous expansion from the Gluteus maximus and where the Tensor fasciæ latæ is inserted between its layers; it is very thin behind and at the upper and medial parts, where it covers the Adductor muscles, but becomes stronger around the knee, where it receives fibrous expansions from the tendon of the Biceps femoris laterally, from the Sartorius medially, and from the Quadriceps femoris in front. The fascia lata is attached, above and behind, to the back of the sacrum and coccyx; laterally, to the iliac crest; in front, to the inguinal ligament and to the superior ramus of the pubis; and medially, to the inferior ramus of the pubis, to the ramus and tuberosity of the ischium, and to the lower border of the sacrotuberous ligament. From its attachment to the iliac crest it descends as a dense fascia over the Gluteus medius to the upper border of the Gluteus maximus, where it splits into two layers, one passing superficial and the other deep to this muscle; at the lower border of the muscle the two layers reunite. Over the lateral surface of the thigh, which is flattened in consequence, the fascia lata is specially thickened and forms a strong band which is termed the *iliotibial tract*. At its upper limit, where it splits into two layers, the tract receives the insertion of the Tensor fasciæ latæ and, posteriorly, it receives the insertion of the greater part of the tendon of the Gluteus maximus. Of the two layers the more superficial ascends on the lateral surface of the Tensor fasciæ latæ to reach the iliac crest; the deeper layer passes upwards and

medially, under cover of the muscle, and blends with the lateral part of the capsule of the hip joint. At its lower limit the iliotibial tract is attached to the lateral condyle of the tibia, but in this situation it is intimately blended with an aponeurotic expansion from the Vastus lateralis. It stands out as a strong, visible ridge on the antero-lateral aspect of the knee, when the leg is extended against gravity. Below, the fascia lata is attached to all the prominent points around the knee joint, viz. the condyles of the femur and tibia, and the head of the fibula. On each side of the patella it is strengthened by transverse fibres from the lower parts of the Vasti, which are attached to and support this bone; of these fibres the lateral are the

FIG. 623.—The left saphenous opening, after the removal of the cribriform fascia.



stronger and are continuous with the iliotibial tract. The fascia lata gives off two intermuscular septa, which are attached to the whole length of the linea aspera of the femur and its prolongations above and below: the lateral and stronger septum, which extends from the insertion of the Gluteus maximus to the lateral condyle, separates the Vastus lateralis in front from the short head of the Biceps femoris behind, and gives partial origin to these muscles; the medial and thinner septum separates the Vastus medialis from the Adductors and the Pectineus. Numerous smaller septa separate the individual muscles and enclose each in a distinct sheath.

The **saphenous opening** (fig. 623).—At the upper and medial part of the thigh the fascia lata presents a large oval aperture; it transmits the great saphenous vein and other smaller vessels, and is termed the *saphenous opening*. The cribriform fascia, which is pierced by the structures passing through the opening, covers the

aperture and must be removed to expose it. The fascia lata in this part of the thigh is described as consisting of a superficial and a deep portion.

The *superficial portion* of the fascia lata is the part on the lateral side of the saphenous opening. It is attached to the crest and anterior superior spine of the ilium, to the whole length of the inguinal ligament, and to the pecten pubis in conjunction with the lacunar ligament (p. 592). From the pubic tubercle it is reflected downwards and laterally, as the *arched falciform margin*, which forms the upper, lateral and lower boundaries of the saphenous opening (fig. 623); this margin overlies and is adherent to the anterior layer of the sheath of the femoral vessels, and the cribriform fascia is attached to it. The upper part of the falciform margin is named the *superior cornu*; its lower part, the *inferior cornu*. The latter is well defined, and is continuous behind the great saphenous vein with the deep portion of the fascia.

The *deep portion* is situated on the medial side of the saphenous opening, and is continuous with the superficial portion at the lower margin of the fossa; traced upwards, it covers the Pectineus, Adductor longus and Gracilis, and, passing behind the sheath of the femoral vessels, to which it is closely united, is attached to the pecten pubis.

From this description it may be observed that the superficial portion of the fascia lata lies in front of the femoral vessels, and the deep portion behind them, so that an apparent aperture (the saphenous opening) exists between the two.

The **Tensor fasciæ latæ** (fig. 622) arises from the anterior 5 cm. of the outer lip of the iliac crest; from the outer surface of the anterior superior iliac spine, and part of the outer border of the notch below it, between the Gluteus medius and Sartorius; and from the deep surface of the fascia lata. It is inserted between the two layers of the iliotibial tract of the fascia lata about the junction of the middle with the upper one-third of the thigh.

Nerve-supply.—The Tensor fasciæ latæ is supplied by the superior gluteal nerve (L. 4 and 5 and S. 1).

Actions.—The Tensor fasciæ latæ tightens the fascia lata and so assists in extension of the knee; it assists also in abduction and in medial rotation of the thigh. In the erect posture, acting from below, it helps to steady the pelvis on the head of the femur; through the iliotibial tract it steadies the condyles of the femur on the tibia and thus helps to maintain the erect attitude. When the thigh is flexed against gravity and the knee is extended, an angular depression becomes apparent immediately below the anterior superior iliac spine. Its lateral boundary is formed by the Tensor fasciæ latæ.

The **Sartorius** (figs. 622, 624, 626), which is the longest muscle in the body, is narrow and ribbon-like; it arises by tendinous fibres from the anterior superior iliac spine and the upper one-half of the notch below it. It crosses the upper and anterior parts of the thigh obliquely, from the lateral to the medial side, then descends vertically as far as the medial side of the knee, where a thin, flattened tendon replaces the fleshy belly. This tendon curves obliquely forwards and expands into a broad aponeurosis which is inserted, in front of the Gracilis and Semitendinosus, into the upper part of the medial surface of the shaft of the tibia (fig. 449). The upper part of the aponeurosis is curved backwards over the upper edge of the tendon of the Gracilis so as to be inserted behind it. An offset, from its upper margin, blends with the capsule of the knee joint, and another, from its lower border, with the fascia on the medial side of the leg.

The relations of this muscle to the femoral artery are important, as it constitutes the chief guide in tying the vessel. In the upper one-third of the thigh it forms the lateral side of the *femoral triangle*, the medial side of which is formed by the medial border of the Adductor longus, and the base by the inguinal ligament; the femoral artery passes through the middle of this triangle from its base to its apex. In the middle one-third of the thigh, the femoral artery is contained in the adductor (sub-sartorial) canal, on the roof of which the Sartorius lies (fig. 626).

Nerve-supply.—The Sartorius is supplied by the femoral nerve (L. 2 and 3).

Actions.—The Sartorius assists in flexing the leg on the thigh, and the thigh on the pelvis, and its action is called for particularly when the two movements are carried out simultaneously. It also helps to abduct the thigh and to rotate it laterally. When these movements are carried out against gravity, the muscle can be both seen and felt in the living subject.

The **Quadriceps femoris** (figs. 622, 624, 626) is the great extensor muscle of the leg, and consists of a large fleshy mass which covers the front and sides of the femur. It is subdivided into separate portions, which have received distinctive names. One occupies the middle of the thigh, and arises from the ilium; from its straight course it is called the *Rectus femoris*. The other three take origin from the shaft of the femur, which they cover from the trochanters to the condyles; that on the lateral side of the femur is termed the *Vastus lateralis*; that on the medial side, the *Vastus medialis*; and that in front, the *Vastus intermedius*.

The **Rectus femoris** (figs. 622, 624, 626) is fusiform in shape, and its superficial fibres are arranged in a bipennate manner, the deep fibres running straight down to the deep aponeurosis. It arises by two tendinous heads: a straight head from the anterior inferior iliac spine, and a reflected head, from a groove above the brim of the acetabulum. The two unite at an acute angle, and spread into an aponeurosis which is prolonged downwards on the anterior surface of the muscle, and from this the muscular fibres arise. The muscle ends in a broad and thick aponeurosis which occupies the lower two-thirds of its posterior surface, and, gradually becoming narrowed into a flattened tendon, is inserted into the base of the patella.

The **Vastus lateralis** (figs. 622, 624, 626) is the largest part of the Quadriceps femoris. It arises by a broad aponeurosis, which is attached to the upper part of the trochanteric line, to the anterior and inferior borders of the greater trochanter, to the lateral lip of the gluteal tuberosity, and to the upper one-half of the lateral lip of the linea aspera (figs. 436 and 438): this aponeurosis covers the upper three-fourths of the muscle, and from its deep surface many fibres take origin. A few additional fibres arise from the tendon of the Gluteus maximus, and from the lateral intermuscular septum between the Vastus lateralis and short head of the Biceps femoris. The fibres form a large fleshy mass which is attached to a strong aponeurosis placed on the deep surface of the lower part of the muscle: this aponeurosis contracts into a flat tendon, which is inserted into the lateral border of the patella, blending with the Quadriceps femoris tendon (*see below*). It gives to the capsule of the knee joint an expansion which extends downwards to be attached to the lateral condyle of the tibia and blends with the iliotibial tract.

The Vastus medialis and Vastus intermedius appear to be inseparably united, but when the Rectus femoris has been reflected a narrow interval will be observed extending upwards from the medial border of the patella between the two muscles, and the separation may be carried to the lower part of the trochanteric line, where, however, the two muscles are frequently continuous.

The **Vastus medialis** (figs. 622, 624, 626) arises from the lower part of the trochanteric line, the spiral line, the medial lip of the linea aspera, the upper part of the medial supracondylar line, the tendons of the Adductor longus and Adductor magnus, and the medial intermuscular septum (figs. 436 and 438). Its fibres are directed downwards and forwards, and are chiefly attached to an aponeurosis which lies on the deep surface of the muscle and is inserted into the medial border of the patella and the Quadriceps femoris tendon (*see below*). An expansion from this tendon reinforces the capsule of the knee joint and is attached below to the medial condyle of the tibia. The lowermost fibres are almost horizontal and form a fleshy bulge in the living subject, medial to the upper half of the patella.

The **Vastus intermedius** (figs. 624, 626) arises from the front and lateral surfaces of the upper two-thirds of the shaft of the femur, and from the lower part of the lateral intermuscular septum. Its fibres end in a superficial aponeurosis which forms the deep part of the Quadriceps femoris tendon and, in addition, gains attachment to the lateral border of the patella and the lateral condyle of the tibia.

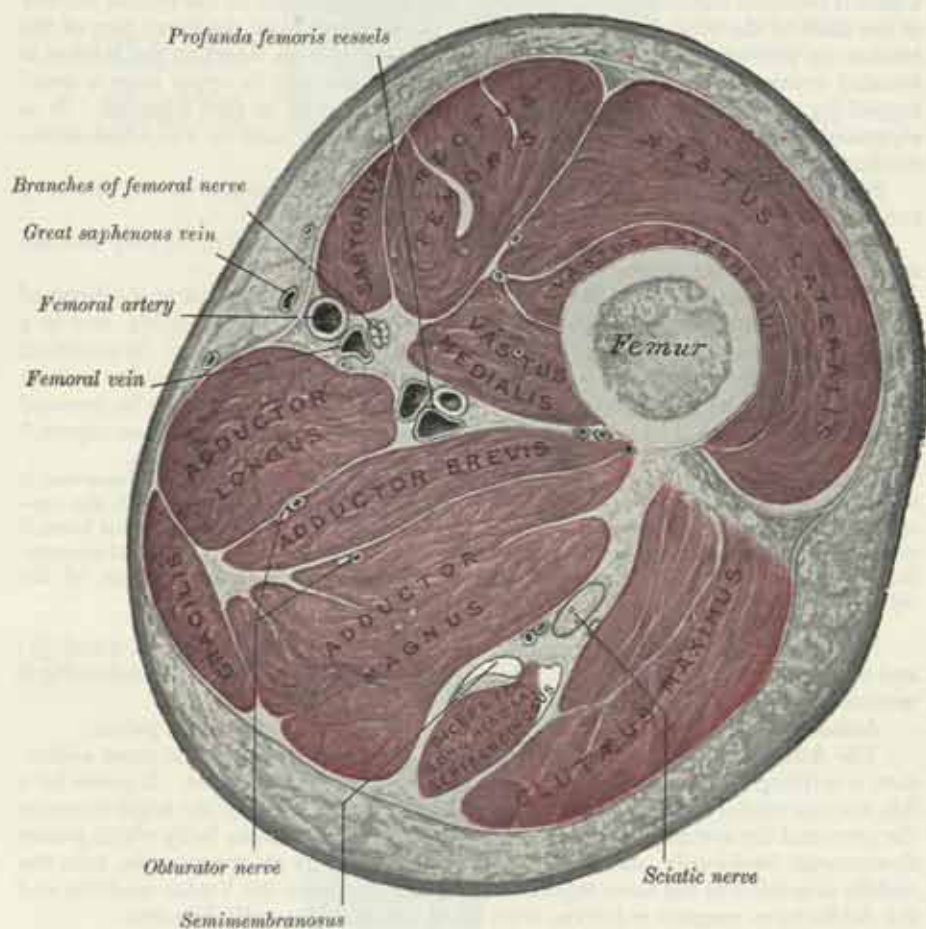
The tendons of the different portions of the Quadriceps unite at the lower part of the thigh to form a single strong tendon which is inserted into the base of the patella, some fibres passing over it to blend with the ligamentum patellæ. The patella may be regarded as a sesamoid bone developed in the tendon of the Quadriceps; and the ligamentum patellæ, which is continued from the apex of the patella to the tubercle of the tibia, may be regarded as the proper tendon of insertion of the muscle, the medial and lateral patellar retinacula (p. 520) being expansions from its borders. The suprapatellar bursa, which usually communicates with the cavity of the knee joint, is situated between the femur and the portion of the Quadriceps tendon above the patella; the deep infrapatellar bursa is interposed between the ligamentum patellæ and the upper part of the front of the tibia (fig. 541).

The **Articularis genu** is a small muscle, usually distinct from the *Vastus intermedius*, but occasionally blended with it; it consists of several muscular bundles which arise from the anterior surface of the lower part of the shaft of the femur and are inserted into the upper part of the synovial membrane of the knee joint.

Nerve-supply.—The *Quadriceps femoris* and the *Articularis genu* are supplied by the femoral nerve (L. 2, 3 and 4).

Actions.—The *Quadriceps femoris* extends the leg upon the thigh. The *Rectus femoris* assists the *Psoas major* and *Iliacus* in supporting the pelvis and

FIG. 624.—A transverse section through the thigh at the level of the apex of the femoral triangle. Four-fifths of natural size.



trunk upon the femur, and it is the balance between the tonus of these muscles and the tonus of the extensors of the hip joints which is responsible for maintaining the erect attitude, so far as these joints are concerned. The *Rectus femoris* also assists in flexing the thigh on the pelvis, or, if the thigh be fixed, it helps to flex the pelvis. The lower fibres of the *Vastus medialis* retain the patella in its groove on the patellar surface of the femur during extension of the knee joint and serve to counteract the natural tendency to lateral displacement of the patella which is attributable to the angulation between the shaft of the femur and the bones of the leg.

It has been suggested, on clinical grounds, that the lower fibres of the *Vastus medialis et lateralis*, are important postural agents ensuring the stability of the knee joint.

The *Articularis genu* pulls the synovial membrane of the knee joint upwards during extension of the leg.

2. THE MEDIAL FEMORAL MUSCLES

Gracilis.
Pectineus.

Adductor longus.
Adductor brevis.

Adductor magnus.

The **Gracilis** (figs. 622, 624, 626) is the most superficial muscle on the medial side of the thigh. It is thin and flattened, broad above, narrow and tapering below. It arises by a thin aponeurosis from the medial margins of the lower one-half of the body of the pubis, the whole length of its inferior ramus and the adjoining part of the ramus of the ischium (fig. 421). The fibres run vertically downwards, and end in a rounded tendon which passes across the medial condyle of the femur posterior to the tendon of Sartorius. It then curves round the medial condyle of the tibia, where it becomes flattened, and is inserted into the upper part of the medial surface of the shaft of the tibia, below the condyle. A few fibres from the lower part of the tendon are prolonged into the deep fascia of the leg. At its insertion the tendon is situated immediately above that of the Semitendinosus, and its upper edge is overlapped by the tendon of the Sartorius, with which it is in part blended. It is separated from the tibial collateral ligament of the knee joint by the tibial intertendinous bursa (p. 527).

Nerve-supply.—The Gracilis is supplied by the obturator nerve (L. 2, 3 and 4).

Actions.—The Gracilis flexes the leg and rotates it medially; it may also act as an adductor of the thigh, when necessary.

The **Pectineus** (fig. 622) is a flat, quadrangular muscle, situated at the front of the upper and medial part of the thigh. It arises from the pecten pubis, and to a slight extent from the surface of bone in front of it, between the iliopectineal eminence and the pubic tubercle, and from the fascia covering the anterior surface of the muscle; the fibres pass downwards, backwards and laterally, to be inserted into the femur along a line leading from the lesser trochanter to the linea aspera.*

Relations.—Its *anterior surface* is in relation with the fascia lata, which separates it from the femoral vessels and great saphenous vein; its *posterior surface*, with the capsule of the hip joint, the Adductor brevis, Obturator externus and the anterior branch of the obturator nerve; its *lateral border*, with the Psoas major and the medial circumflex femoral vessels; its *medial border*, with the upper or lateral margin of the Adductor longus.

Nerve-supply.—The Pectineus is supplied by the femoral nerve (L. 2 and 3); and by the accessory obturator (L. 3), when this nerve is present. Occasionally it receives a branch from the obturator nerve.

Actions.—The Pectineus † adducts the thigh and flexes it on the pelvis.

The **Adductor longus** (figs. 625, 626), the most superficial of the three adductors, is a triangular muscle, lying in the same plane as the Pectineus. It arises by a flat, narrow tendon which is attached to the front of the pubis in the angle between the crest and the symphysis. It soon expands into a broad fleshy belly which passes downwards, backwards, and laterally, and is inserted, by an aponeurosis, into the middle one-third of the linea aspera of the femur, between the Vastus medialis and the Adductores magnus et brevis, with all of which it is usually blended.

Relations.—Its *anterior surface* is in relation with the spermatic cord, the fascia lata, by which it is separated from the great saphenous vein, and, near its insertion, with the femoral artery and vein and the Sartorius: its *posterior surface*, with the Adductores brevis et magnus, the anterior branch of the obturator nerve, and near its insertion with the profunda femoris vessels; its *lateral border*, with the Pectineus; its *medial border*, with the Gracilis.

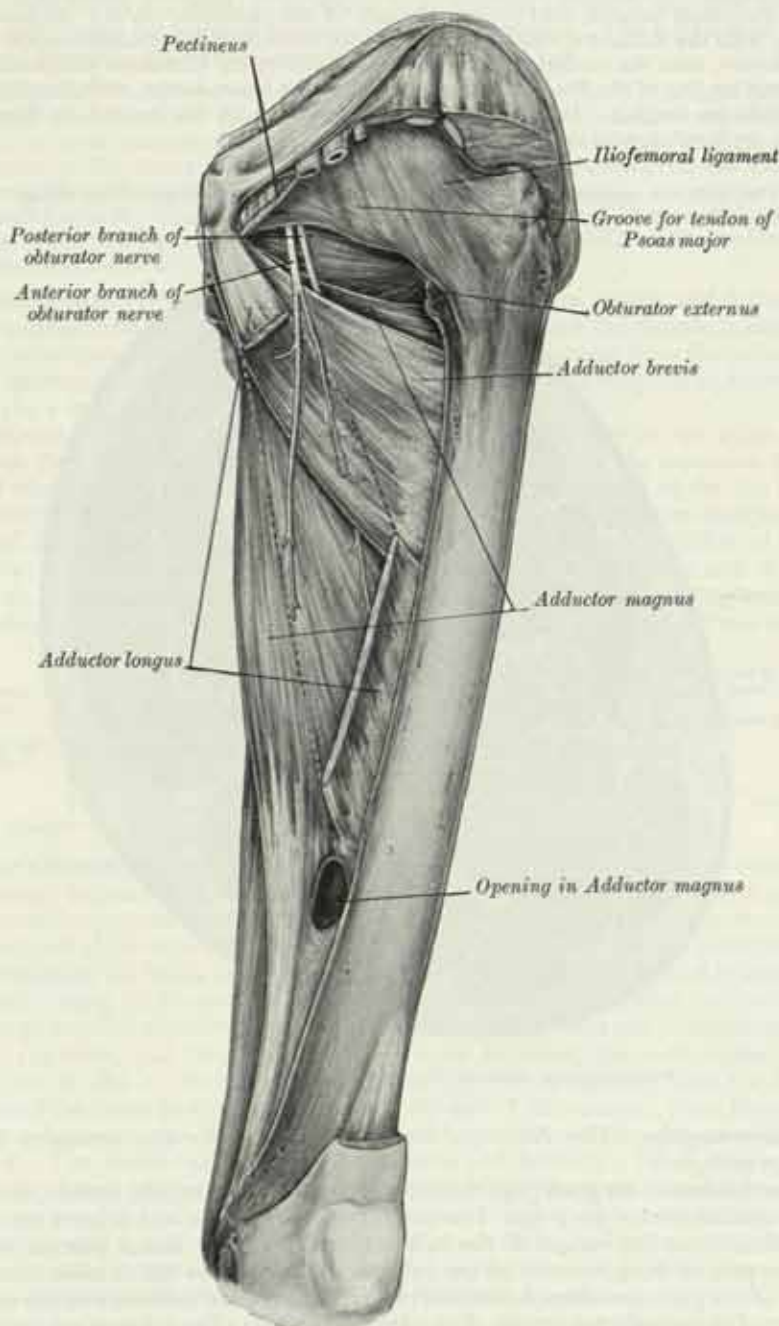
Nerve-supply.—The Adductor longus is supplied by the anterior division of the obturator nerve (L. 2 and 3).

* The Pectineus may consist of two incompletely separated strata: the lateral or dorsal stratum, which is constant, is supplied by a branch from the femoral nerve, or, in the absence of this branch, by the accessory obturator nerve; the medial or ventral stratum, when present, is a derivative of the adductor group of muscles, and is supplied by the obturator nerve.—A. M. Paterson, *Journal of Anatomy and Physiology*, 26, 1891.

† See footnote, p. 667.

Applied Anatomy.—The Adductor longus is liable to be severely strained in those who ride much on horseback, or it may be ruptured by suddenly gripping the saddle. Occasionally the tendon of origin becomes ossified, constituting the 'rider's bone'.

FIG. 625.—The adductor muscles of the left thigh. Viewed from in front.



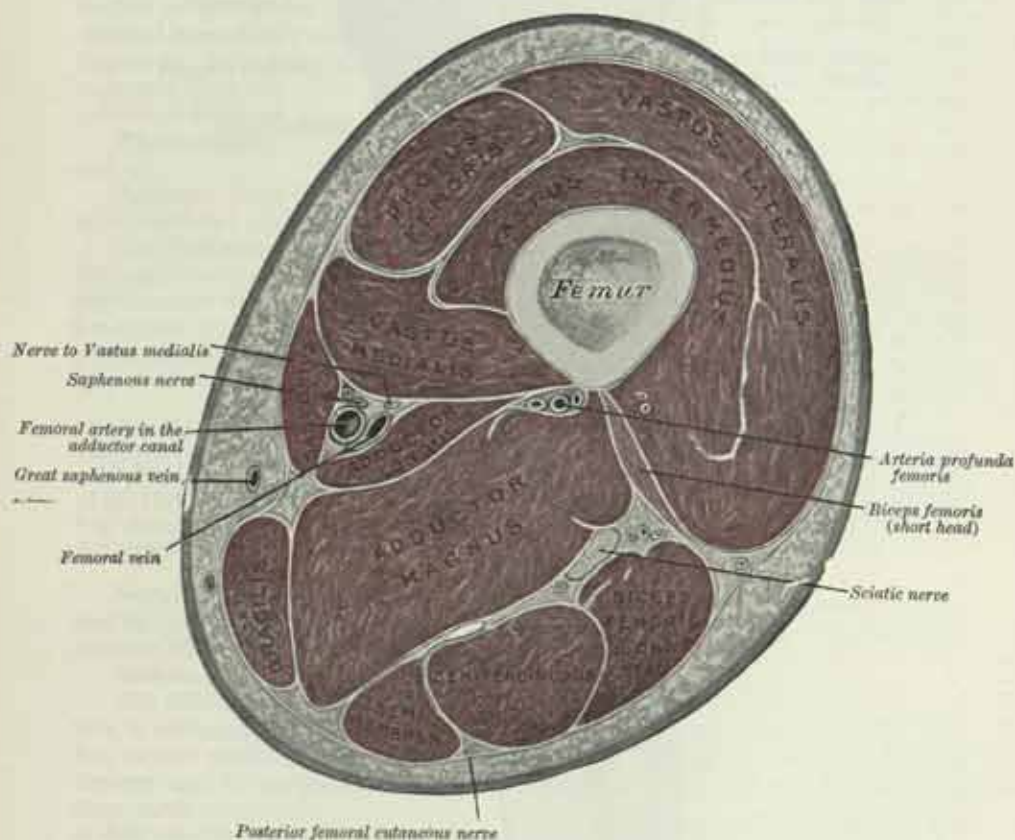
A portion of the Adductor longus has been excised, and the two heads of the Rectus femoris, which are not labelled, have been divided above the point where they unite.

The **Adductor brevis** (figs. 624, 625) is situated behind the Pectineus and Adductor longus. It is somewhat triangular in form, and arises by a narrow origin from the anterior surface of the body and the outer surface of the inferior ramus of the pubis, in the interval between the Gracilis and Obturator externus. Its fibres

passing backwards, laterally, and downwards, are inserted by an aponeurosis into the femur, along the line leading from the lesser trochanter to the linea aspera, and into the upper part of the linea aspera immediately behind the Pectineus and the upper part of the Adductor longus.

Relations.—Its *anterior surface* is in relation with the Pectineus, Adductor longus, arteria profunda femoris, and anterior branch of the obturator nerve; its *posterior surface*, with the Adductor magnus, and posterior branch of the obturator nerve; its *upper border*, with the medial circumflex femoral artery, the Obturator externus, and conjoined tendon of the Psoas major and Iliacus; its *lower border*, with the Gracilis and Adductor magnus. It is pierced near its insertion by the second, or first and second, perforating arteries.

FIG. 626.—A transverse section through the middle of the thigh. Four-fifths of natural size.



Nerve-supply.—The Adductor brevis is supplied by the obturator nerve (L. 2, 3 and 4).

The **Adductor magnus** (figs. 624, 625, 626) is a large triangular muscle, situated on the medial side of the thigh. It arises from a small part of the inferior ramus of the pubis, from the ramus of the ischium, and from the lateral portion of the inferior part of the tuberosity of the ischium. Those fibres which arise from the ramus of the pubis are short, horizontal in direction, and are inserted into the medial margin of the gluteal tuberosity of the femur, medial to the Gluteus maximus; * those from the ramus of the ischium are directed downwards and laterally with different degrees of obliquity, to be inserted, by means of a broad aponeurosis, into the linea aspera and the upper part of the medial supracondylar line. The medial portion of the muscle, composed principally of the fibres arising from the tuberosity of the ischium, forms a thick fleshy mass which descends almost vertically, and ends

* These uppermost fibres are sometimes described as a separate muscle—the *Adductor minimus*—which is situated somewhat in front of the other parts of the muscle.

about the lower one-third of the thigh in a rounded tendon, which can readily be felt on deep pressure immediately above the adductor tubercle (p. 415). It is inserted into the adductor tubercle on the medial condyle of the femur, and is connected by a fibrous expansion to the medial supracondylar line. At the insertion of the muscle, there is a series of osseo-aponeurotic openings, formed by tendinous arches attached to the bone. The upper four openings are small, and give passage to the perforating branches of the *arteria profunda femoris*. The lowest is of large size, and transmits the femoral vessels to the popliteal fossa.

Relations.—Its *anterior surface* is in relation with the Pectineus, Adductores brevis et longus, the femoral and profunda vessels, and the posterior branch of the obturator nerve; a bursa intervenes between the highest part of the muscle and the lesser trochanter of the femur; its *posterior surface*, with the sciatic nerve, the Gluteus maximus, Biceps femoris, Semitendinosus and Semimembranosus. Its *superior border* lies parallel with the Quadratus femoris, the transverse branch of the medial circumflex femoral artery passing between them; its *medial border* is in relation with the Gracilis, Sartorius and fascia lata.

Nerve-supply.—The Adductor magnus is a composite muscle and derives its nerve-supply from two sources. The true adductor part of the muscle is supplied by the obturator nerve (L. 3 and 4); the part which takes origin from the tuberosity of the ischium is a derivative of the hamstring muscles and is supplied by the sciatic nerve (L. 4 and 5).

Actions.—The three Adductores are powerful adductors of the thigh. In addition they produce lateral rotation of the femur and, with the exception of the ischial fibres of the Adductor magnus which are weak extensors of the hip joint, they flex the thigh on the pelvis. They are especially used in horse exercise, the sides of the saddle being grasped between the knees by the contraction of these muscles; when the limb has been abducted, they rotate it laterally and draw it medially, carrying the thigh across that of the opposite side. In walking and running, they assist in drawing forwards the lower limb.

3. THE MUSCLES OF THE GLUTEAL REGION (figs. 627, 628)

Gluteus maximus.	Obturator internus.
Gluteus medius.	Gemellus superior.
Gluteus minimus.	Gemellus inferior.
Piriformis.	Quadratus femoris.

Obturator externus.

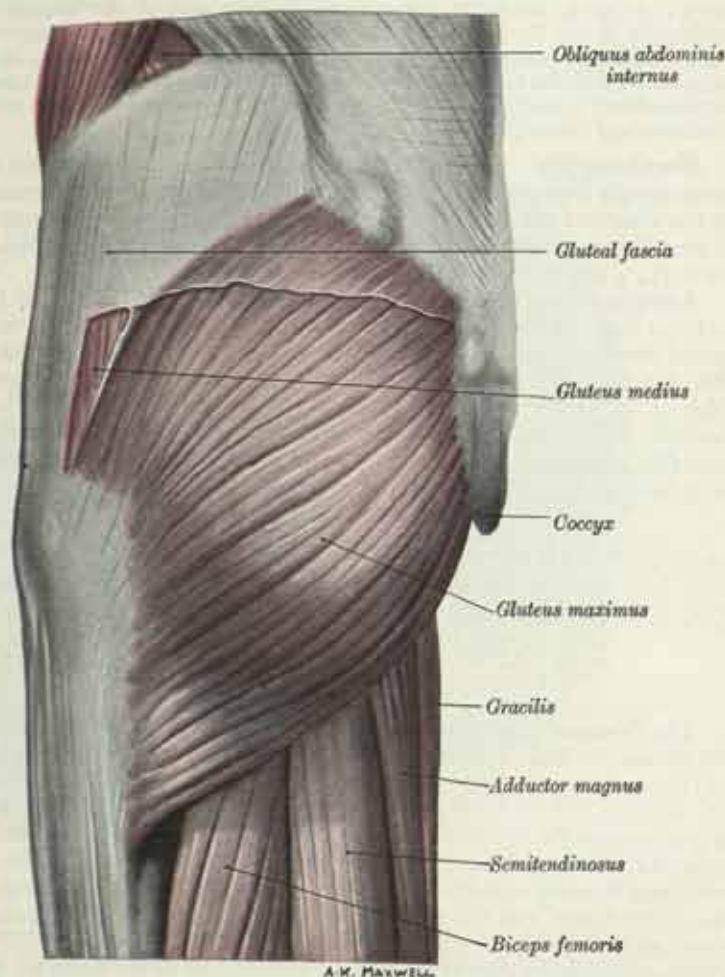
The **Gluteus maximus** (fig. 627) is the largest and most superficial muscle in the gluteal region. It is a broad and thick fleshy mass of a quadrilateral shape, and forms the prominence of the buttock. Its large size is one of the most characteristic features of the muscular system in man, connected as it is with the power he has of maintaining the trunk in the erect position. The muscle is remarkably coarse in structure, being made up of fasciculi lying parallel with one another, and collected into large bundles separated by fibrous septa. It arises from the posterior gluteal line of the ilium, and the rough portion of bone, including the crest, immediately above and behind it; from the aponeurosis of the Erector spinæ; from the dorsal surface of the lower part of the sacrum and the side of the coccyx; from the sacrotuberous ligament, and from the fascia (gluteal aponeurosis) covering the Gluteus medius. The fibres run obliquely downwards and laterally; those forming the upper and larger portion of the muscle, together with the superficial fibres of the lower portion, end in a thick tendinous lamina which passes across the greater trochanter, and is inserted into the iliotibial tract of the fascia lata; the deeper fibres of the lower portion of the muscle are inserted into the gluteal tuberosity of the femur between the Vastus lateralis and Adductor magnus.

Three *bursæ* are usually found in relation with the deep surface of this muscle. One, of large size and generally multilocular, separates it from the greater trochanter (*trochanteric bursa of Gluteus maximus*); a second is found between the tendon of the muscle and that of the Vastus lateralis (*gluteofemoral bursa*); a third, often wanting, is situated on the tuberosity of the ischium (*ischial bursa of Gluteus maximus*).

Relations.—Its *superficial surface* is in relation with a thin fascia which separates it from the subcutaneous tissue; its *deep surface*, with the ilium, sacrum, coccyx, and sacrotuberous ligament, part of the Gluteus medius, Piriformis, Gemelli, Obturator

internus, Quadratus femoris, the tuberosity of the ischium, greater trochanter, the origins of the Biceps femoris, Semitendinosus, Semimembranosus and the Adductor magnus. The superficial division of the superior gluteal artery reaches the deep surface of the muscle by passing between the Piriformis and the Gluteus medius; the inferior gluteal and internal pudendal vessels and the sciatic, pudendal, and posterior femoral cutaneous nerves and muscular branches from the sacral plexus, issue from the pelvis below the Piriformis. The first perforating artery and the terminal branches of the medial circumflex femoral artery are also found under cover of the lower part

FIG. 627.—The left Gluteus maximus muscle.



A portion of the strong gluteal fascia has been removed to expose a part of the Gluteus medius.

of the muscle. Its *upper border* is thin, and overlies the Gluteus medius. Its *lower border* is free and prominent, and is crossed by the horizontal gluteal fold, which marks the upper limit of the back of the thigh on the surface (fig. 573).

Nerve-supply.—The Gluteus maximus is supplied by the inferior gluteal nerve (L. 5 and S. 1 and 2).

Actions.—When the Gluteus maximus takes its fixed point from the pelvis, it extends the thigh and brings it into line with the trunk. Taking its fixed point below, it supports the pelvis and the trunk upon the head of the femur, and, so far as the hip joint is concerned, the maintenance of the erect attitude is ensured by the balanced tone of the Gluteus maximus and the other extensors of the joint, on the one hand, and of the flexors of the joint, on the other hand. Its most powerful

action is to raise the trunk, after stooping, by rotating the pelvis backwards on the head of the femur. It is a tensor of the fascia lata, and through the iliotibial tract it steadies the femur on the tibia during standing, when the extensor muscles are relaxed.

The **Gluteus medius** is a broad, thick muscle which is situated on the outer surface of the pelvis. Its posterior one-third is covered by the *Gluteus maximus*; its anterior two-thirds is superficial and is covered only by a strong layer of deep fascia (fig. 627). It arises from the outer surface of the ilium between the iliac crest and posterior gluteal line above, and the anterior gluteal line below; it also arises from the strong fascia which covers the upper part of its outer surface. The fibres converge to a flattened tendon, which is inserted into the oblique ridge directed downwards and forwards on the lateral surface of the greater trochanter of the femur. A bursa (*trochanteric bursa of Gluteus medius*) separates the tendon from the anterosuperior part of the lateral surface of the trochanter, over which it glides.

The **Gluteus minimus** (fig. 628), the smallest of the Glutei, is placed immediately under cover of the preceding muscle. It is fan-shaped, arising from the outer surface of the ilium between the anterior and inferior gluteal lines, and, behind, from the margin of the greater sciatic notch. The fibres converge to the deep surface of an aponeurosis, and this ends in a tendon which is inserted into a ridge on the lateral part of the anterior surface of the greater trochanter of the femur, and gives an expansion to the capsule of the hip joint. A bursa (*trochanteric bursa of Gluteus minimus*) is interposed between the tendon and the medial part of the anterior surface of the greater trochanter.

Between the *Gluteus medius* and *Gluteus minimus* are the deep branches of the superior gluteal vessels, and the superior gluteal nerve. The reflected tendon of the *Rectus femoris* and the capsule of the hip joint are placed deep to the *Gluteus minimus*.

Nerve-supply.—Both the *Gluteus medius* and the *Gluteus minimus* are supplied by the superior gluteal nerve (L. 4 and 5 and S. 1).

Actions.—Both the preceding muscles, acting from the pelvis, abduct the thigh and their anterior fibres rotate it medially.

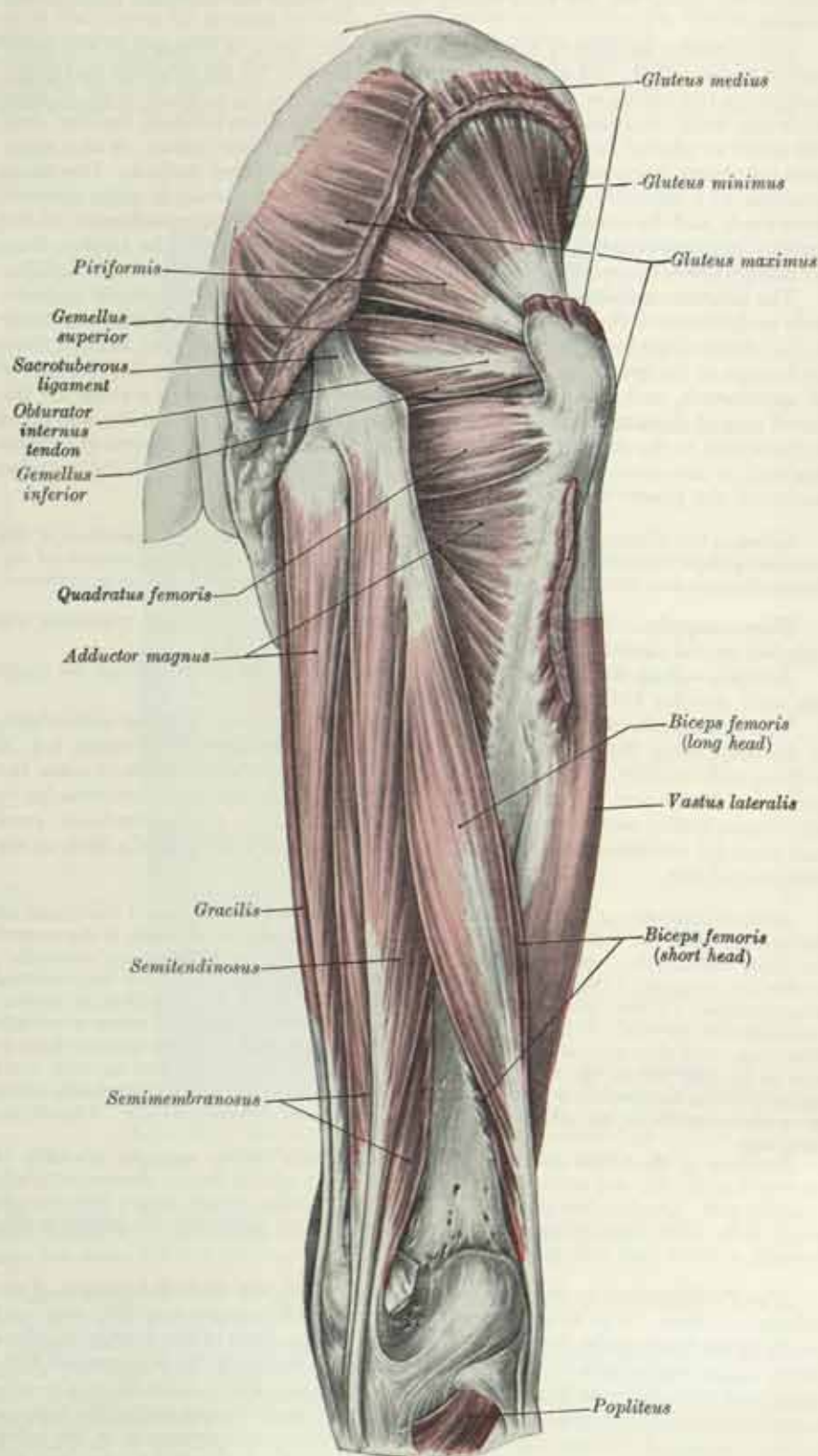
The two muscles play an all-important part in maintaining the poise and balance of the body when the foot of the opposite side is raised from the ground, e.g. in walking and running. In these circumstances the body-weight tends to make the pelvis sag downwards on the unsupported side, and *that tendency is counteracted by the Gluteus medius and minimus of the supporting side, which, acting from below, exert such powerful traction on the hip bone that the pelvis is actually raised a little on the unsupported side.*

Applied Anatomy.—The stabilising effect of the Glutei (*medius* and *minimus*) on the pelvis, when the foot of the opposite side is raised from the ground, is dependent on three conditions, viz.:—(1) the two muscles must be functioning normally; (2) the components of the hip joint, which forms the fulcrum, must have their normal relationships; (3) the neck of the femur must be intact and must exhibit its normal angulation to the shaft of the bone. When any one of these three conditions is not fulfilled (e.g.—(1) paralysis of the Glutei, *medius* and *minimus*; (2) congenital dislocation of the hip joint; (3) ununited fracture of the neck of the femur or coxa vara) the stabilising mechanism is upset and the pelvis sinks on the unsupported side when the patient stands on the affected limb. This is known clinically as the 'Trendelenberg sign.'

Paralysis of the Glutei medius et minimus is the most serious muscular disability in the region of the hip, and patients suffering from this condition have a characteristically lurching gait. On the other hand, when these two muscles remain intact, even though many of the other muscles which act on the hip joint are paralysed, the patient is able to walk, or even run, with remarkably little disability.

The **Piriformis** (fig. 628) lies almost parallel with the posterior margin of the *Gluteus medius*. It is situated partly within the pelvis on its posterior wall, and partly at the back of the hip joint. It arises from the front of the sacrum by three fleshy digitations, attached to the portions of bone between the pelvic sacral foramina, and to the grooves leading from the foramina (fig. 262): a few fibres also arise from the margin of the greater sciatic foramen, and from the upper part of the anterior (pelvic) surface of the sacrotuberous ligament. The muscle passes out of the pelvis through the greater sciatic foramen, and is inserted by a rounded tendon into the

FIG. 628.—The muscles of the gluteal region and the posterior muscles of the thigh.
Right side.



upper border of the greater trochanter of the femur, behind and above, but often partly blended with, the common tendon of the Obturator internus and Gemelli.

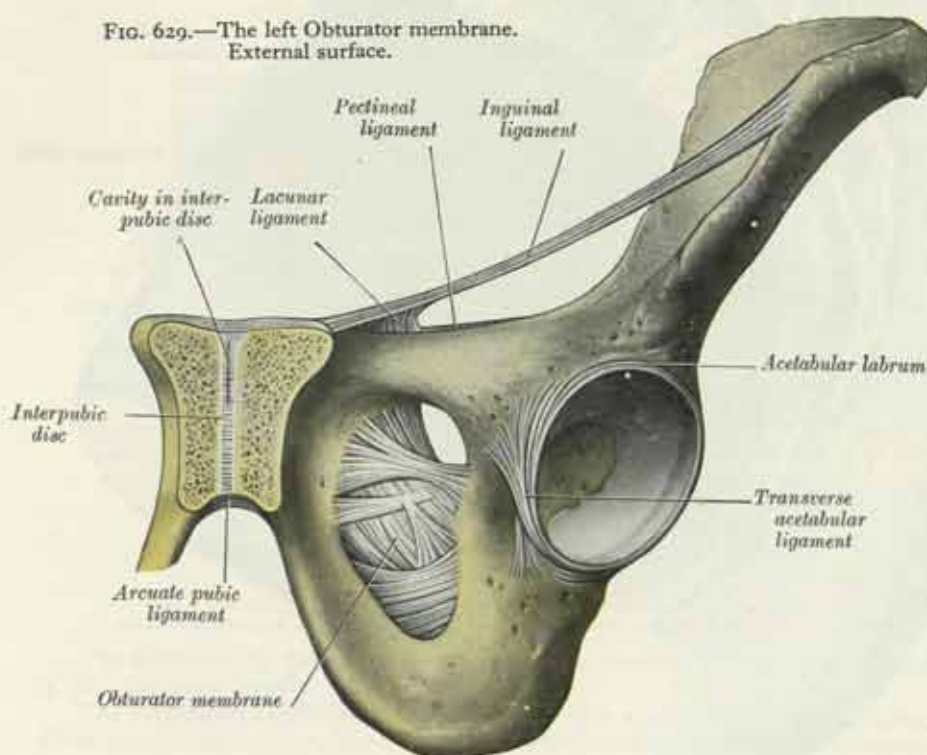
Relations.—*Within the pelvis* the anterior surface of the Piriformis is in relation with the rectum (especially on the left side), the sacral plexus of nerves and branches of the internal iliac vessels; its *posterior surface*, with the sacrum. *Outside the pelvis*, its *anterior surface* is in contact with the posterior surface of the ischium and capsule of the hip joint; its *posterior surface*, with the Gluteus maximus. Its *upper border* is in relation with the Gluteus medius, and the superior gluteal vessels and nerve; its *lower border*, with the Coccygeus and Gemellus superior. The inferior gluteal and internal pudendal vessels, the sciatic, posterior femoral cutaneous and pudendal nerves, and muscular branches from the sacral plexus, appear in the buttock in the interval between the Piriformis and Gemellus superior. The muscle is frequently pierced by the common peroneal nerve.

Nerve-supply.—The Piriformis is supplied by twigs from S. 1 and 2.

Actions.—The Piriformis rotates the thigh laterally.*

The **obturator membrane** (fig. 629) is a thin, fibrous sheet which nearly closes the obturator foramen. Its fibres are arranged in interlacing bundles mainly trans-

FIG. 629.—The left Obturator membrane.
External surface.



verse in direction; the uppermost bundle is attached to the obturator tubercles and completes the obturator canal for the passage of the obturator vessels and nerve. The membrane is attached to the sharp margin of the obturator foramen except at its lower lateral angle, where it is fixed to the pelvic surface of the ramus of the ischium, i.e. within the margin of the foramen. Both Obturator muscles take origin

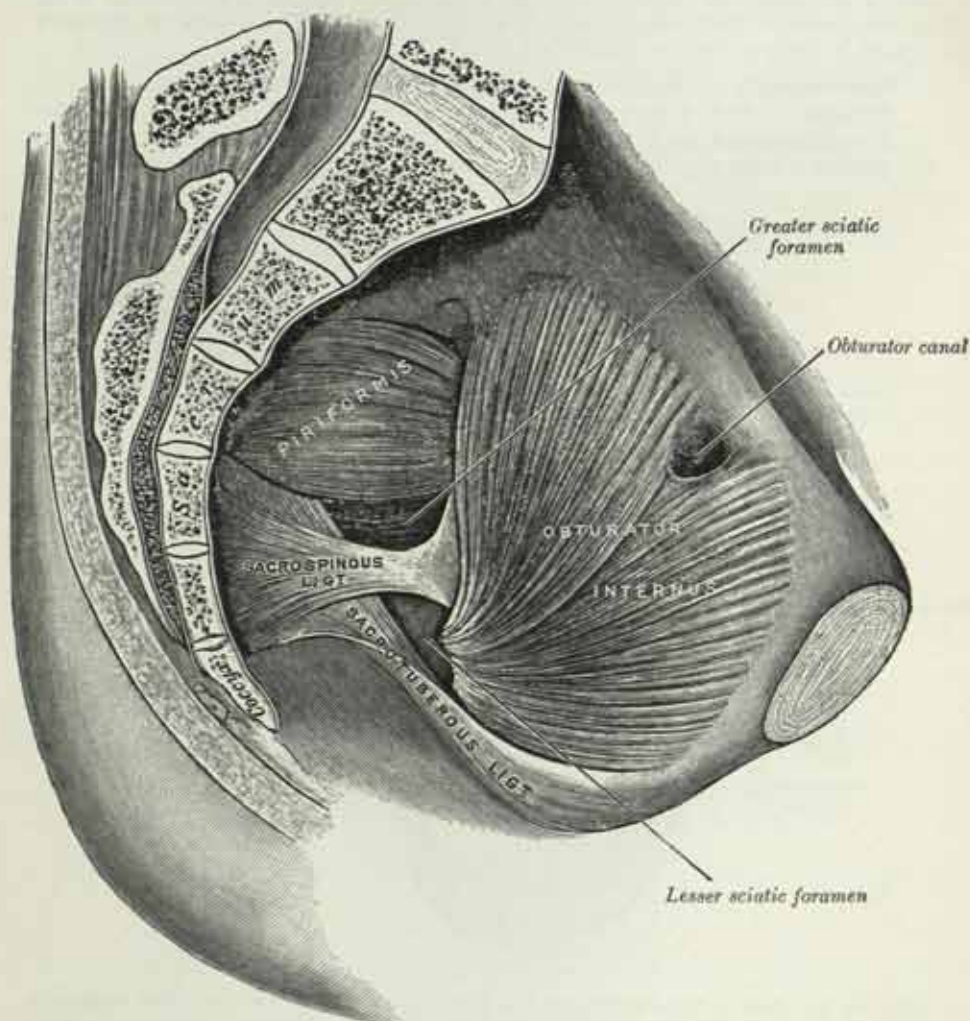
* It is probable that the short muscles which lie in intimate relation to the hip joint exercise a more important function as postural muscles than as prime movers. They are so situated that they are able to exert a controlling influence on the direction of the axis of the neck of the femur during movements of the joint. In particular they determine and limit the degree of medial rotation which would otherwise be associated with flexion of the joint.

Owing to the shortness of their fibres these muscles are admirably adapted to come into action when, during relaxation of the larger muscles, sudden strains threaten the integrity of the capsule, especially on its posterior surface. This arrangement obviates the need for the provision of ligaments strong enough to resist such strains. Ligaments of sufficient strength would be so bulky that they would interfere with the mobility of the joint. On the other hand, the muscular bulk is placed at a distance from the actual joint and in no way interferes with freedom of movement.

from this membrane, and some of the fibres of the pubofemoral ligament of the hip joint are attached to its inferior surface.

The **Obturator internus** (fig. 630) is situated partly within the true pelvis, and partly at the back of the hip joint. It arises from the inner surface of the antero-lateral wall of the pelvis, where it surrounds the greater part of the obturator foramen, being attached to the inferior ramus of the pubis, the ramus of the ischium and to the pelvic surface of the hip bone below and behind the pelvic brim, reaching from the upper part of the greater sciatic foramen above and behind, to the obturator

FIG. 630.—The left Obturator internus. Pelvic surface.



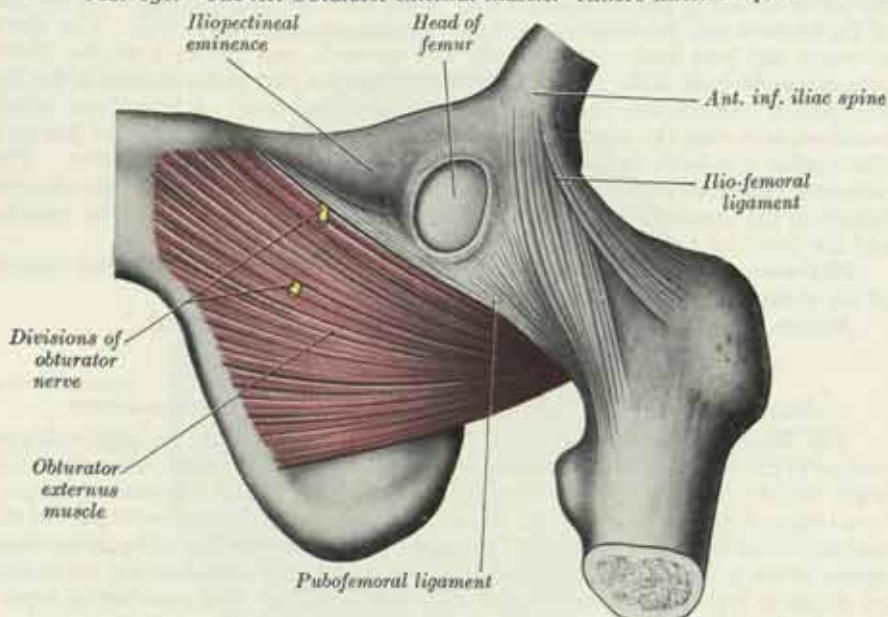
foramen below and in front (fig. 423). It also arises from the medial part of the pelvic surface of the obturator membrane, from the tendinous arch which completes the canal for the passage of the obturator vessels and nerve, and to a slight extent from the obturator fascia, which covers the muscle. The fibres converge rapidly towards the lesser sciatic foramen and end in four or five tendinous bands in the deep surface of the muscle; these bands make a right-angled bend over the grooved surface of the ischium between its spine and tuberosity. The grooved surface is covered by smooth cartilage, which is separated from the tendon by a bursa, and presents one or more ridges corresponding with the furrows between the tendinous bands. These bands leave the pelvis through the lesser sciatic foramen and unite into a single flattened tendon, which passes horizontally across the capsule of the hip joint, and, after receiving the attachments of the Gemelli, is inserted into the fore part of the

medial surface of the greater trochanter of the femur, above and in front of the trochanteric fossa. A bursa, narrow and elongated in form, is usually found between the tendon and the capsule of the hip joint; it occasionally communicates with the bursa between the tendon and the ischium.

Relations.—*Within the pelvis*, the *anterolateral surface* of the muscle is in relation with the obturator membrane and inner surface of the lateral wall of the pelvis; its *pelvic surface*, with the obturator fascia, and the origin of the Levator ani, and with the sheath which surrounds the internal pudendal vessels and pudendal nerve (p. 603). The pelvic surface forms the lateral boundary of the ischiorectal fossa. *Outside the pelvis*, the muscle is covered by the Gluteus maximus, is crossed by the sciatic nerve, and rests on the back of the hip joint. As the tendon of the Obturator internus emerges from the lesser sciatic foramen it is overlapped both above and below by the two Gemelli, which form a muscular canal for it; near its insertion the Gemelli pass in front of the tendon and form a groove in which it lies.

Nerve-supply.—The nerve to Obturator internus derives its fibres from L. 5 and S. 1 and 2.

FIG. 631.—The left Obturator externus muscle. Antero-inferior aspect.



Note.—The bursa of Psoas major tendon, which in this specimen communicated with the synovial cavity of the hip joint, has been opened to expose the head of the femur.

The **Gemelli** (fig. 628) are two small muscular fasciculi, adjacent to the tendon of the Obturator internus.

The **Gemellus superior**, the smaller of the two, arises from the dorsal surface of the spine of the ischium, blends with the upper part of the tendon of the Obturator internus, and is inserted with it into the medial surface of the greater trochanter of the femur. It is sometimes missing.

Nerve-supply.—The Gemellus superior is supplied by the nerve to the Obturator internus (L. 5 and S. 1 and 2).

The **Gemellus inferior** arises from the upper part of the tuberosity of the ischium, immediately below the groove for the Obturator internus tendon. It blends with the lower part of the tendon of the Obturator internus, and is inserted with it into the medial surface of the greater trochanter.

Nerve-supply.—The Gemellus inferior is supplied by the nerve to the Quadratus femoris (L. 4 and 5 and S. 1).

Actions.—The Obturator internus and the Gemelli rotate the thigh laterally.*

The **Quadratus femoris** (fig. 628) is a flat, quadrilateral muscle, between the Gemellus inferior and the upper margin of the Adductor magnus; it is separated from the latter by the transverse branch of the medial circumflex femoral artery. It arises from the upper part of the external border of the tuberosity of the ischium.

* See footnote, p. 667.

and is inserted into a small tubercle on the upper part of the trochanteric crest of the femur, and for a short distance into the bone below. As it passes to its insertion the muscle lies posterior to the articular capsule of the hip joint and the neck of the femur, but it is separated from them by the tendon of the Obturator externus and the ascending branch of the medial circumflex femoral artery. A bursa is often found between the front of this muscle and the lesser trochanter.

Nerve-supply.—The nerve to Quadratus femoris derives its fibres from L. 4 and 5 and S. 1.

Action.—The Quadratus femoris is a lateral rotator of the thigh.*

The **Obturator externus** (fig. 631) is a flat, triangular muscle which covers the outer surface of the anterior wall of the pelvis. It arises from the margin of bone immediately around the medial side of the obturator foramen, viz. from the rami of the pubis, and the ramus of the ischium; it also arises from the medial two-thirds of the outer surface of the obturator membrane, and from the tendinous arch which completes the canal for the passage of the obturator vessels and nerves. The fibres springing from the ramus of the ischium extend for a short distance on to the pelvic surface of the bone, where they obtain a narrow origin between the margin of the foramen and the attachment of the obturator membrane (p. 667). The fibres converge and pass backwards, laterally and upwards, and end in a tendon which runs across the back of the neck of the femur and lower part of the capsule of the hip joint and is inserted into the trochanteric fossa of the femur. A bursal sac, which communicates with the synovial cavity of the hip joint, may be interposed between this tendon and both the capsule of the hip joint and neck of the femur. The obturator vessels lie between the muscle and the obturator membrane; the anterior branch of the obturator nerve reaches the thigh by passing in front of the muscle, and the posterior branch by piercing it (fig. 631).

Nerve-supply.—The Obturator externus is supplied by the posterior branch of the obturator nerve (L. 3 and 4).

Action.—The Obturator externus is a lateral rotator of the thigh.*

4. THE POSTERIOR FEMORAL MUSCLES (fig. 628)

Biceps femoris.

Semitendinosus.

Semimembranosus.

The **Biceps femoris** (figs. 624, 626, 628) is situated on the posterolateral surface of the thigh. It has two heads of origin: one, the long head, arises from the lower and medial impression on the upper part of the ischial tuberosity (fig. 424) by a tendon common to it and the Semitendinosus, and from the lower part of the sacrotuberous ligament; the other, the short head, from the lateral lip of the linea aspera of the femur, between the Adductor magnus and Vastus lateralis, extending up almost as high as the insertion of the Gluteus maximus; from the lateral supracondylar line to within 5 cm. of the lateral condyle; and from the lateral intermuscular septum. The fibres of the long head form a fusiform belly which passes downwards and laterally across the sciatic nerve to end in an aponeurosis; this aponeurosis covers the posterior surface of the muscle, receives on its deep surface the fibres of the short head, and gradually narrows down into a tendon which is inserted into the lateral side of the head of the fibula, and by a small slip into the lateral condyle of the tibia. This tendon forms the lateral hamstring; its main part embraces the fibular collateral ligament and is inserted into the head of the fibula. The remainder splits into three lamellæ, the intermediate of which is inserted into the fibular collateral ligament while the other lamellæ pass respectively superficial and deep to this ligament to be attached to the lateral condyle of the tibia.† The common peroneal nerve descends along the medial border of the tendon and separates it, below, from the lateral head of the Gastrocnemius.

Nerve-supply.—The Biceps femoris is supplied by the sciatic nerve; the long head through the tibial portion (S. 1, 2 and 3), the short head through the common peroneal portion (L. 5 and S. 1).

The **Semitendinosus** (figs. 626, 628), remarkable for the great length of its tendon of insertion, is situated on the posteromedial surface of the thigh. It arises from the lower and medial impression on the upper part of the tuberosity of the ischium, by a tendon common to it and the long head of the Biceps femoris; it also arises from an aponeurosis connecting the adjacent surfaces of the two muscles to

* See footnote, p. 667

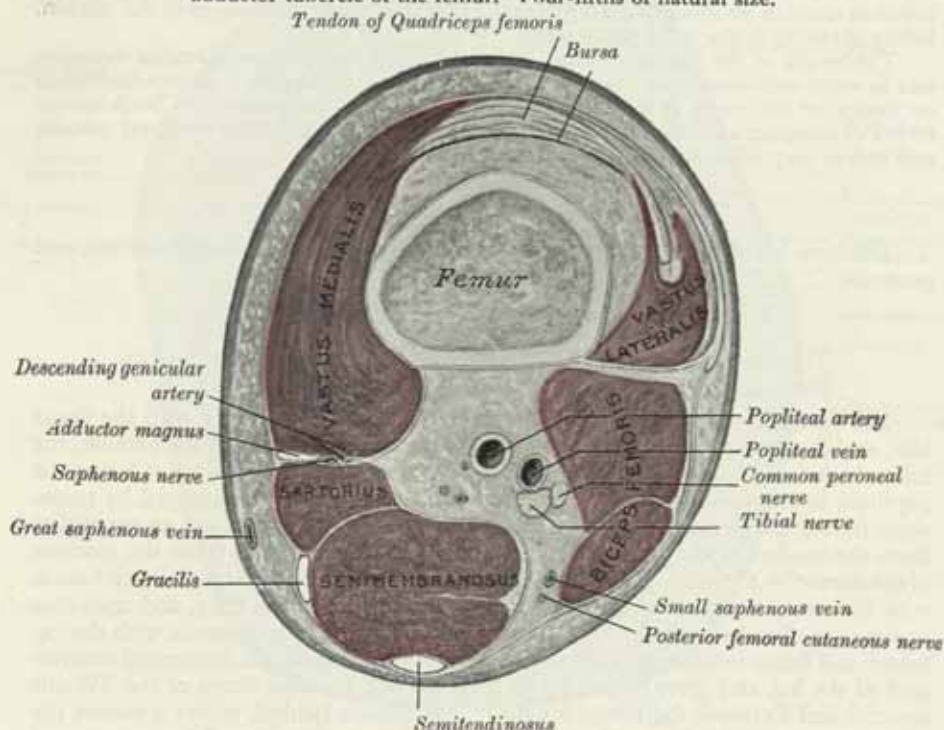
† R. S. Sneath, *J. Anat., Lond.*, 89, 1955.

the extent of about 7.5 cm. from their origin. The muscle is fusiform and ends a little below the middle of the thigh in a long, round tendon, which lies on the surface of the Semimembranosus muscle; the tendon curves around the medial condyle of the tibia, passes over the tibial collateral ligament of the knee joint, from which it is separated by a bursa, and is inserted into the upper part of the medial surface of the shaft of the tibia behind the insertion of the Sartorius and below that of the Gracilis. At its insertion it is united with the tendon of the Gracilis and gives off a prolongation to the deep fascia of the leg. A tendinous intersection is usually present about the middle of the muscle.

Nerve-supply.—The Semitendinosus is supplied by the sciatic nerve through the tibial portion (L. 4 and 5 and S. 1 and 2).

The **Semimembranosus** (figs. 626, 628, 632), so called from its membranous tendon of origin, is situated at the back and medial side of the thigh. It arises by a thick tendon from the upper and lateral impression on the tuberosity of the ischium (fig. 424), above and lateral to the Biceps femoris and Semitendinosus, and is

FIG. 632.—A transverse section through the thigh, 4 cm. above the adductor tubercle of the femur. Four-fifths of natural size.



inserted into the groove on the back of the medial condyle of the tibia. The tendon of origin expands into an aponeurosis which passes downwards under cover of the Semitendinosus and long head of the Biceps femoris; from this aponeurosis muscular fibres arise, and converge to another aponeurosis which covers the lower part of the posterior surface of the muscle and narrows into the tendon of insertion. The tendon of insertion gives off certain fibrous expansions: one, of considerable size, passes upwards and laterally to be inserted into the intercondylar line and lateral condyle of the femur, forming the oblique popliteal ligament of the knee joint; a second is continued downwards to the fascia which covers the Popliteus muscle; while a few fibres join the tibial collateral ligament of the knee joint and the fascia of the leg. The muscle overlaps the upper part of the popliteal vessels and is itself overlapped and partly hidden by the Semitendinosus muscle throughout its whole extent (fig. 628).

The tendons of insertion of the Semitendinosus and Semimembranosus form the medial hamstrings.

Nerve-supply.—The Semimembranosus is supplied by the sciatic nerve through the tibial portion (L. 4 and 5 and S. 1).

Actions.—The posterior femoral muscles, acting from above, flex the leg on the thigh. Acting from below, they serve to support the pelvis on the head of the femur, and they draw the trunk backwards when it is raised from the stooping position. When the knee is semiflexed, the Biceps femoris can act as a lateral rotator, and the Semimembranosus and Semitendinosus as medial rotators of the leg.

When the knee is flexed against resistance, the tendon of the Biceps can be felt without difficulty on the lateral side of the depression which overlies the popliteal fossa. On the medial side of the fossa, the tendons of the Gracilis, which is the more medial, and the Semitendinosus stand out very sharply, and in the interval between them the Semimembranosus tendon can be felt, though less distinctly as it is more deeply situated.

Applied Anatomy.—In disease of the knee joint, contraction of the hamstring tendons is a frequent complication; this causes flexion of the leg, and a partial dislocation of the tibia backwards, with a slight degree of lateral rotation, probably due to the action of the Biceps femoris. The hamstring tendons occasionally require subcutaneous division. The relation of the common peroneal nerve, which lies in close apposition to the medial border of the tendon of the Biceps femoris, must always be borne in mind in dividing this tendon, and a free incision with exposure of the tendon, before division, is the safer proceeding.

The length of the hamstring muscles, when relaxed, shows considerable variation and in some individuals the muscles are so short that they impose a serious limitation on flexion of the trunk at the hip joints while the knees are extended. Such movements as stooping are then effected almost entirely by flexion of the vertebral column and this is very liable to lead to excessive flexion strains.

III. THE MUSCLES OF THE LEG

The muscles of the leg may be divided into three groups: anterior, lateral, and posterior.

I. THE ANTERIOR CRURAL MUSCLES (fig. 634)

Tibialis anterior.

Extensor hallucis longus.

Extensor digitorum longus.

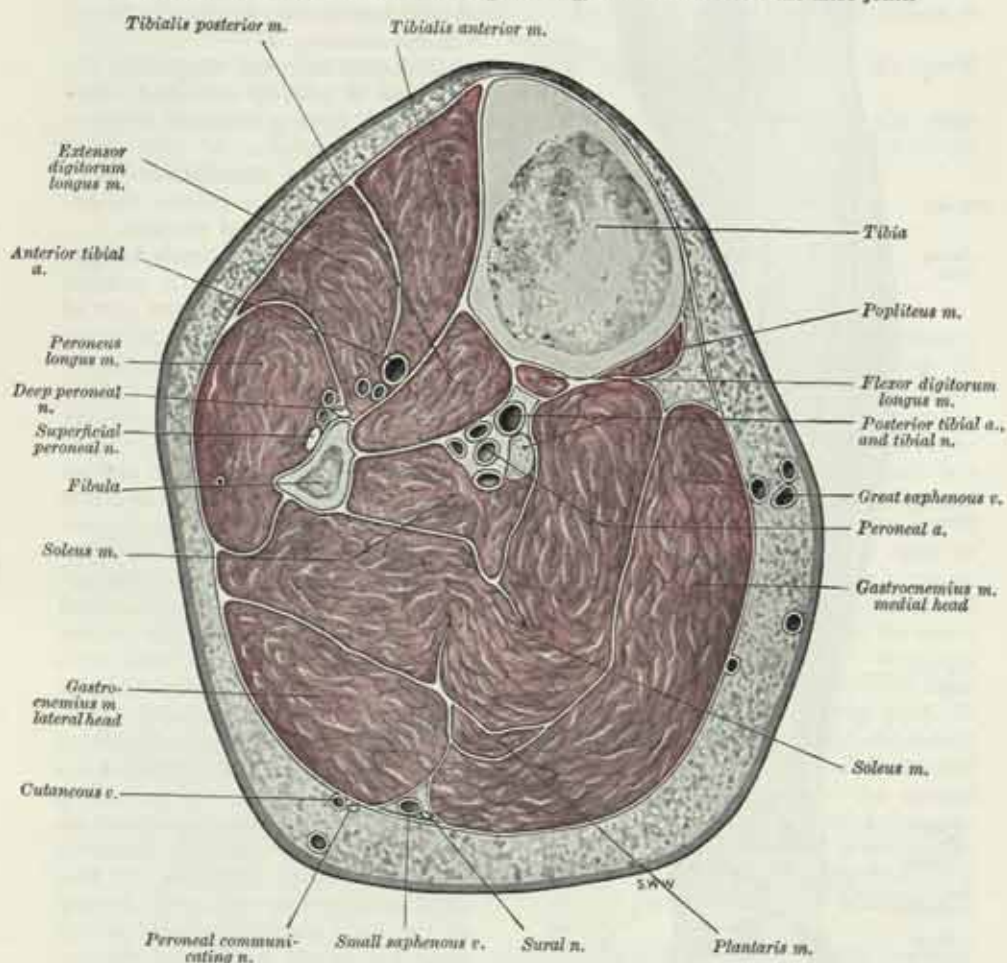
Peroneus tertius.

The **fascia cruris** or deep fascia of the leg is continuous above with the fascia lata, and is attached around the knee to the patella, the ligamentum patellæ, the tubercle and condyles of the tibia and the head of the fibula. Behind, it forms the popliteal fascia, which covers the popliteal fossa; here it is strengthened by transverse fibres, and perforated by the small saphenous vein. It receives an expansion from the tendon of the Biceps femoris laterally, and expansions from the tendons of the Sartorius, Gracilis, Semitendinosus and Semimembranosus medially; it blends with the periosteum covering the subcutaneous surface of the tibia, and with that covering the head and malleolus of the fibula; below, it is continuous with the extensor and flexor retinacula (p. 683). It is thick and dense in the upper and anterior part of the leg, and gives origin, by its deep surface, to some fibres of the Tibialis anterior and Extensor digitorum longus; it is thinner behind, where it covers the Gastrocnemius and Soleus. On the lateral side of the leg it gives off the *anterior and posterior crural intermuscular septa*, which are attached respectively to the anterior and posterior borders of the fibula; in the anterior and posterior crural regions the fascia also gives off several slender processes which enclose the individual muscles. A broad, transverse, intermuscular septum, called the *deep transverse fascia of the leg* (p. 679), intervenes between the superficial and deep muscles on the back of the leg.

The **Tibialis anterior** (figs. 633, 634) is situated on the lateral side of the tibia; it is thick and fleshy above, tendinous below. It arises from the lateral condyle and upper one-half or two-thirds of the lateral surface of the shaft of the tibia; from the adjoining part of the anterior surface of the interosseous membrane; from the deep surface of the fascia cruris; and from the intermuscular septum between it and the Extensor digitorum longus. The fibres run vertically downwards, and end in a tendon which is apparent on the anterior surface of the muscle at the lower one-third of the leg; it passes through the medial compartments of the superior and inferior extensor retinacula, inclines towards the medial side of the foot, and is inserted into the medial and under surfaces of the medial cuneiform bone, and the adjoining part of the base of the first metatarsal bone. This muscle overlaps the anterior tibial vessels and deep peroneal nerve in the upper part of the leg.

Actions.—When the foot is on the ground and under load, the *Tibialis anterior*, acting from above, elevates the first metatarsal and the medial cuneiform bones and rotates them laterally, thus raising the summit of the longitudinal arch and, at the same time, inverting the foot (cf. actions of *Peroneus longus*, p. 675); in this way it initiates the movements by which the resting foot is transformed into the active arched form (p. 544). Acting from below, it assists in maintaining the balance of the body by drawing the leg forwards at the talocrural joint, when there is a tendency to overbalance in a backward direction.

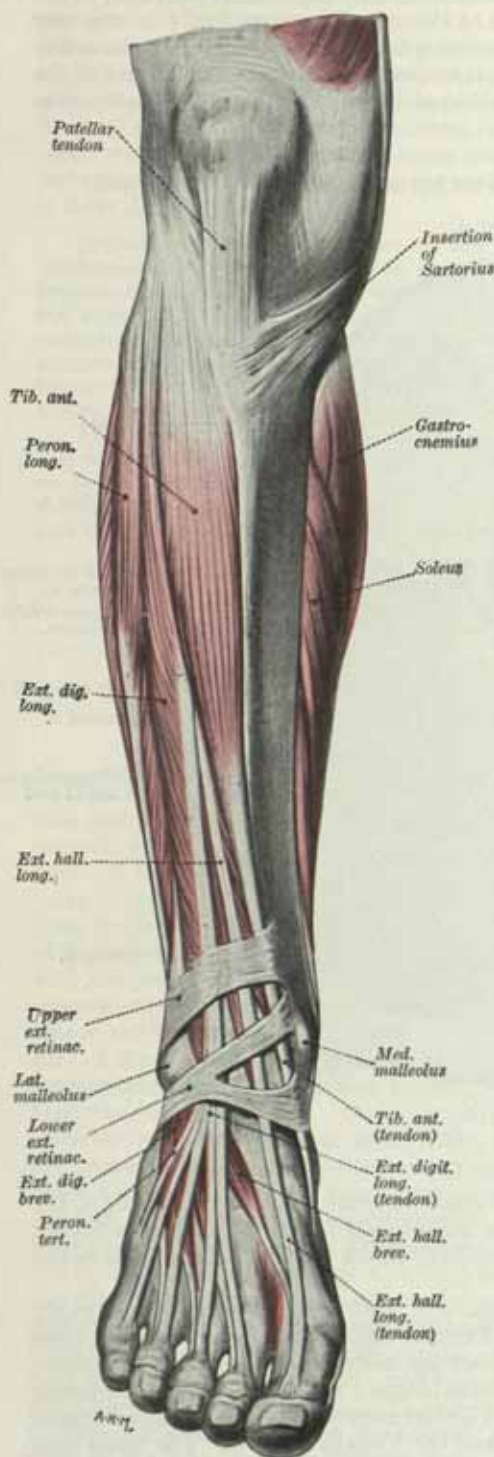
FIG. 633.—A transverse section through the leg, four inches below the knee joint.



When the foot is off the ground, the *Tibialis anterior* acts as a dorsiflexor of the talocrural joint and its tendon can be seen immediately lateral to the anterior border of the tibia and traced downwards and medially across the front of the ankle to the medial side of the foot.

The **Extensor hallucis longus** (figs. 634, 636) lies between, and is partly hidden by, the *Tibialis anterior* and the *Extensor digitorum longus*. It arises from the anterior surface of the fibula for about the middle two-fourths of its extent, medial to the origin of the *Extensor digitorum longus*; it also arises from the anterior surface of the interosseous membrane to a similar extent. The anterior tibial vessels and deep peroneal nerve lie between it and the *Tibialis anterior*. The fibres pass downwards, and end in a tendon which occupies the anterior border of the muscle. It passes deep to the superior and through the inferior extensor retinaculum, crosses to the medial side of the anterior tibial vessels near the talocrural joint, and is inserted into the dorsal aspect of the base of the distal phalanx of the great toe. Opposite the metatarsophalangeal articulation a thin prolongation is given off from

FIG. 634.—Muscles on extensor aspect of leg.
(From Quain's *Anatomy*, XI. Edition.)



each side of the tendon and covers the dorsal surface of the joint. An expansion from the medial side of the tendon is usually inserted into the base of the proximal phalanx.

Actions.—The Extensor hallucis longus extends the phalanges of the great toe; in continued action it dorsiflexes the foot. In the living subject its tendon can readily be identified on the lateral side of the tendon of Tibialis anterior.

It should be noted that, when the great toe is actively extended, relatively little force is required to overcome the extension of the distal phalanx, whereas considerable force must be exerted to overcome the extension of the proximal phalanx.

The **Extensor digitorum longus** (figs. 633, 634, 636) is a pennate muscle, situated at the lateral part of the front of the leg. It arises from the lateral condyle of the tibia, the upper three-fourths of the anterior surface of the shaft of the fibula, the upper part of the anterior surface of the interosseous membrane, the deep surface of the fascia cruris, the anterior crural intermuscular septum and the septum between it and the Tibialis anterior. In the upper part of the leg the anterior tibial vessels and deep peroneal nerve intervene between the muscle and the Tibialis anterior and, at a lower level, the Extensor hallucis longus also intervenes between them. The tendon of the Extensor digitorum longus passes behind the superior extensor retinaculum and within the loop of the inferior extensor retinaculum (p. 684) in company with the Peroneus tertius (fig. 640). It divides into four slips, which run forward on the dorsum of the foot, and are inserted in the same way as the tendons of the Extensor digitorum in the upper limb (p. 634). Opposite the metatarsophalangeal joints the tendons to the second, third, and fourth toes are each joined on the lateral side by a tendon of the Extensor digitorum brevis. A *dorsal digital expansion* is formed on the dorsal aspect of the proximal phalanx, comparable with the expansion formed on the fingers and, like that expansion, receiving contributions from the Lumbrical and Interosseous muscles

(p. 634). Narrowing as it approaches the proximal interphalangeal joint, the expansion divides into three slips—an intermediate, which is inserted into the base of the middle phalanx; and two collateral slips, which, after uniting with each other on the dorsal surface of the middle phalanx, are inserted into the base of the distal phalanx.

Actions.—The Extensor digitorum longus extends the toes, and, when its action is continued, dorsiflexes the foot.

The **Peroneus (fibularis) tertius** (figs. 634, 641) is a part of the Extensor digitorum longus, and might be described as its fifth tendon. The fibres belonging to this tendon arise from the lower one-third or more of the anterior surface of the fibula, the lower part of the anterior surface of the interosseous membrane and the anterior crural intermuscular septum. The tendon passes behind the superior and within the loop of the inferior extensor retinaculum in company with the Extensor digitorum longus (fig. 640), and is inserted into the medial part of the dorsal surface of the base of the fifth metatarsal bone, but often spreads into a thin sheet which extends forwards along the medial border of the shaft of the bone. This muscle is sometimes missing.

Actions.—The Peroneus tertius dorsiflexes the foot; it also raises the lateral border of the foot, i.e. everts the foot.

Nerve-supply.—All the anterior crural muscles are supplied by the deep peroneal nerve. The Tibialis anterior is innervated by L. 4 and 5, but the others receive their supply from L. 5 and S. 1.

2. THE LATERAL CRURAL MUSCLES

Peroneus longus.

Peroneus brevis.

The **Peroneus (fibularis) longus** (figs. 633, 637, 638), which is the more superficial of the two muscles, is situated at the upper part of the lateral side of the leg. It arises from the head and upper two-thirds of the lateral surface of the shaft of the fibula, from the deep surface of the fascia cruris, and from the anterior and posterior crural intermuscular septa: occasionally also by a few fibres from the lateral condyle of the tibia. Between its attachments to the head and body of the fibula, there is a gap through which the common peroneal nerve passes. It ends in a long tendon, which runs behind the lateral malleolus, in a groove common to it and the tendon of the Peroneus brevis, behind which it lies; the groove is converted into a canal by the superior peroneal retinaculum, and the tendons in it are contained in a common synovial sheath (fig. 641). The tendon then runs obliquely forwards across the lateral side of the calcaneus, below the peroneal trochlea and the tendon of the Peroneus brevis, and under cover of the inferior peroneal retinaculum (p. 684); it crosses the lateral side of the cuboid bone, and then runs on the under surface of that bone in a groove which is converted into a canal by the long plantar ligament (fig. 550). It crosses the sole of the foot obliquely, and is inserted by two slips into (a) the lateral side of the base of the first metatarsal bone and (b) the lateral side of the medial cuneiform bone; occasionally a third slip is attached to the base of the second metatarsal bone. The tendon changes its direction at two points: (a) below the lateral malleolus, (b) on the cuboid bone; in both of these situations it is thickened, and, in the latter, a sesamoid fibrocartilage (sometimes a bone) is usually developed in its substance. A second synovial sheath invests the tendon as it crosses the sole of the foot.

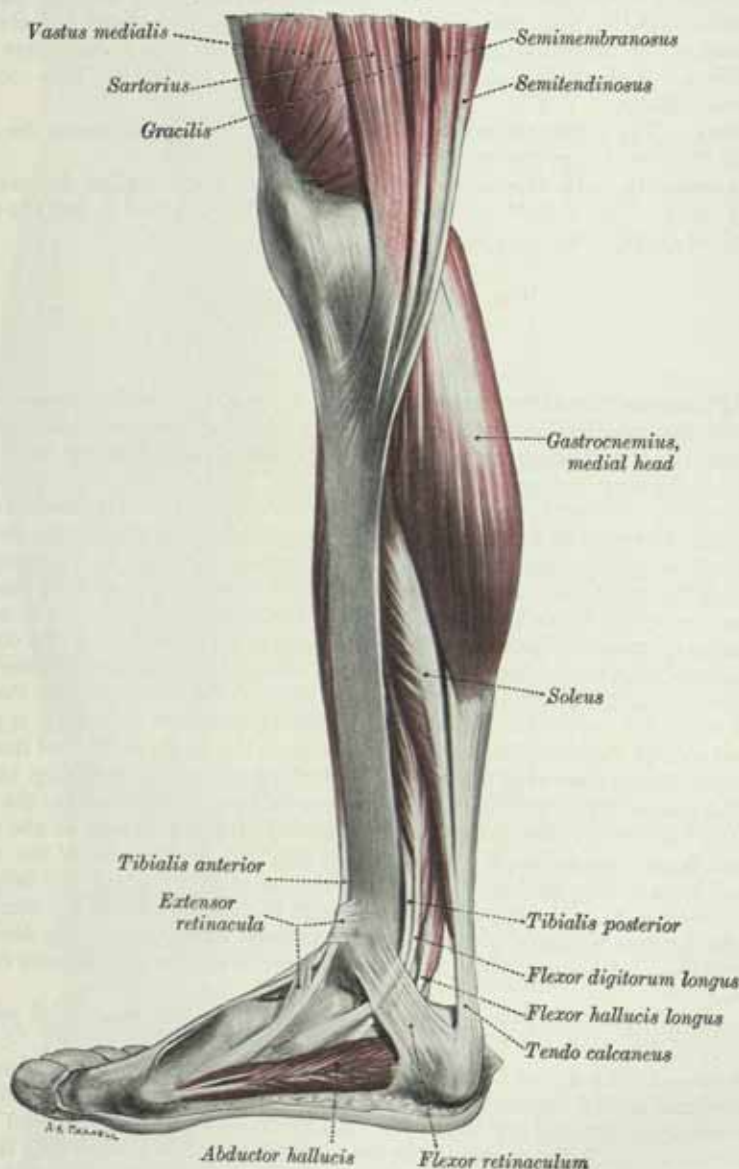
Nerve-supply.—The Peroneus longus is supplied by the superficial peroneal nerve (L. 5 and S. 1).

Actions.—In the active erect posture (p. 545) the Peroneus longus produces depression and medial rotation of the first metatarsal and medial cuneiform bones and so enables the inverted foot to remain plantigrade. Taking its fixed point below, the Peroneus longus helps to steady the leg on the foot; this is especially the case in standing on one leg, when the tendency of the superincumbent weight is to throw the leg medially. As a consequence of the oblique direction of its tendon across the sole it is an important agent in maintaining the transverse and lateral longitudinal arches of the foot in the active erect posture (p. 545), and in this respect it is associated with the Tibialis posterior. When the foot is off the ground, it is an evorter and can be seen as a narrow muscular ridge on the lateral aspect of the leg when it is actively contracting.

The **Peroneus (fibularis) brevis** (figs. 636, 637) arises from the lower two-thirds of the lateral surface of the shaft of the fibula, in front of the Peroneus longus; and from the anterior and posterior crural intermuscular septa. The fibres pass vertically downwards, and end in a tendon which runs behind the lateral malleolus

along with, but in front of, that of the Peroneus longus, the two tendons passing deep to the superior peroneal retinaculum and being enclosed in a common synovial sheath (p. 685). It then runs forwards on the lateral side of the calcaneus above the peroneal trochlea and the tendon of the Peroneus longus, and is inserted into the tubercle on the base of the fifth metatarsal bone, on its lateral side.

FIG. 635.—The muscles of the right leg, viewed from the medial side.
(From Quain's *Anatomy*, XI. Edition.)



On the lateral surface of the calcaneus the tendons of the Peronei longus et brevis occupy separate, osseo-aponeurotic canals formed by the calcaneus and the inferior peroneal retinaculum; each tendon is enveloped by a forward prolongation of the common synovial sheath (fig. 641).

Nerves.—The Peroneus brevis is supplied by the superficial peroneal nerve (L. 5 and S. 1).

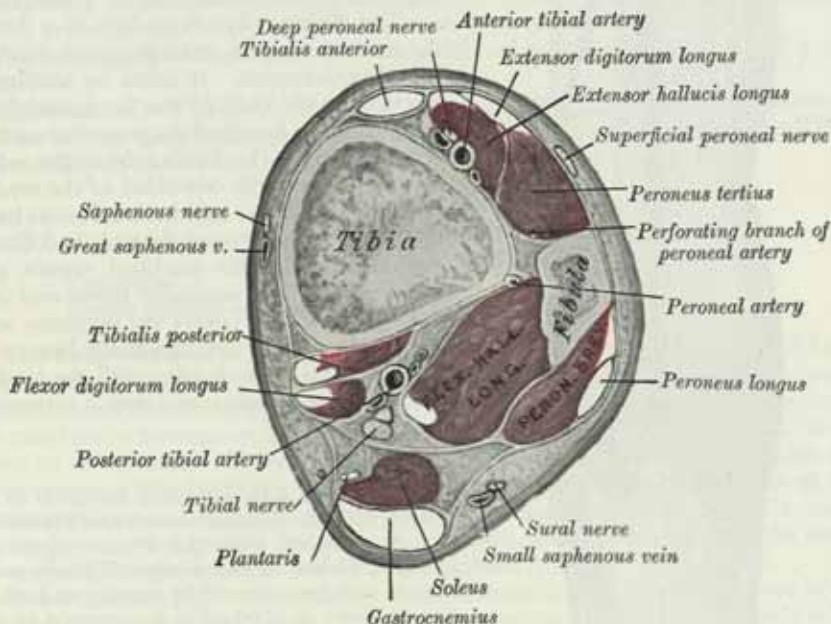
Action.—The Peroneus brevis prevents over-inversion of the foot and so protects the ligaments which are put on the stretch by this movement (lateral part of interosseous talocalcanean, lateral talocalcanean and calcaneofibular). It participates in producing eversion of the foot.

Acting from below, the *Peroneus brevis* helps to steady the leg on the foot (cf. *Peroneus longus*, p. 675).

3. THE POSTERIOR CRURAL MUSCLES

The muscles of the back of the leg are subdivided into two groups—superficial and deep. Those of the superficial group constitute a powerful muscular mass, forming the calf of the leg. Their large size is one of the most characteristic features

FIG. 636.—A transverse section through the leg, 6 cm. above the tip of the medial malleolus.



of the muscular apparatus in man, and bears a direct relation to his erect attitude and his mode of progression.

Superficial Group (fig. 637)

Gastrocnemius.

Soleus.

Plantaris.

The **Gastrocnemius** (figs. 633, 637), which is the most superficial muscle of the group, forms the greater part of the calf. It arises by two heads, which are connected to the condyles of the femur by strong, flat tendons. The medial and larger head takes its origin from a depression at the upper and posterior part of the medial condyle behind the adductor tubercle, and from a slightly raised area on the popliteal surface of the femur just above the medial condyle. The lateral head arises from an impression on the lateral surface of the lateral condyle and from the lower part of the corresponding supracondylar line. Both heads also arise from the subjacent part of the capsule of the knee joint. Each head spreads out into a tendinous expansion which covers the posterior surface of the corresponding part of the muscle. From the anterior surfaces of these tendinous expansions, muscular fibres are given off; those of the medial head extending lower than those of the lateral. The two heads remain separate and their fibres are inserted into a broad aponeurosis which is developed on the anterior surface of the muscle. The aponeurosis, gradually contracting, unites with the tendon of the *Soleus*, and with it forms the *tendo calcaneus*, (p. 678).

Relations.—The fascia cruris separates the *superficial surface* of the muscle from the small saphenous vein, and the peroneal communicating and sural nerves; the common peroneal nerve crosses the lateral head of the muscle, lying partly under cover of *Biceps femoris*. The *deep surface* is in relation with the oblique popliteal ligament,

FIG. 637.—Muscles of calf; superficial layer. (From Quain's *Anatomy*, XI. Edition.)



the Popliteus, Soleus, Plantaris, popliteal vessels and tibial nerve. A bursa, which, in some cases, communicates with the cavity of the knee joint, is placed in front of the tendon of the medial head. The tendon of the lateral head sometimes contains a sesamoid fibrocartilage or bone, where it plays over the corresponding condyle; and one is occasionally found in the tendon of the medial head.

Nerve-supply.—The Gastrocnemius is supplied by the tibial nerve (S. 1 and 2).

The **Soleus** (figs. 633, 637) is a broad flat muscle situated immediately in front of the Gastrocnemius. It arises by tendinous fibres from the back of the head, and from the upper one-fourth of the posterior surface of the shaft of the fibula; from the soleal line and the middle one-third of the medial border of the tibia; and from a fibrous band which stretches between the tibia and fibula, and arches over the popliteal vessels and tibial nerve. The muscular fibres end in a flat tendon which covers the posterior surface of the muscle, and, gradually becoming thicker and narrower, joins with the tendon of the Gastrocnemius, and with it forms the tendo calcaneus.

Relations.—Its *superficial surface* is in relation with the Gastrocnemius and Plantaris; its *deep surface*, with the Flexor digitorum longus, Flexor hallucis longus, Tibialis posterior, and posterior tibial vessels and tibial nerve, from all of which it is separated by the deep transverse fascia of the leg.

Nerve-supply.—The Soleus is supplied by two branches from the tibial nerve (L. 5, S. 1 and 2).

The Gastrocnemius and Soleus form a muscular mass which is occasionally described as the *Triceps suræ*; its tendon of insertion is the tendo calcaneus.

The **tendo calcaneus** (fig. 637) is the thickest and strongest tendon in the body. It is about 15 cm. long, and begins near the middle of the leg, but its anterior surface receives fleshy fibres from the Soleus, almost to its lower end. It gradually narrows and thickens until it reaches a level about 4 cm. above the calcaneus; below this it expands and is inserted into the middle of the posterior surface of the calcaneus, a bursa being interposed between the tendon and the upper part of this surface.

Actions.—The muscles of the calf are the chief plantar-flexors of the foot; they possess considerable power, and are usually of large size.

The Gastrocnemius provides the propelling force in walking, running and leaping, but the Soleus probably is mainly concerned with steadying the leg on the

foot in the standing position and its postural function is of more importance than its value as a prime mover. In standing the weight is usually borne more on the fore-foot than on the heel, and a strong brace is required behind the talocrural joint to maintain the posture. In this position the Soleus projects from under cover of the Gastrocnemius, especially on the lateral side and its fleshy belly extends to a lower level.

The **Plantaris** (fig. 637) arises from the lower part of the lateral supracondylar line, and from the oblique popliteal ligament. It forms a small fusiform belly, from 7 cm. to 10 cm. long; this ends in a long slender tendon, which crosses obliquely between the Gastrocnemius and Soleus and runs along the medial border of the tendo calcaneus to be inserted with it into the posterior part of the calcaneus. This muscle is sometimes double, and at other times missing. Occasionally, its tendon is lost in the flexor retinaculum (p. 684), or in the fascia of the leg.

Nerve-supply.—The Plantaris is supplied by the tibial nerve (L. 4 and 5 and S. 1).

Actions.—The Plantaris is the rudiment of a large muscle, the tendon of which is inserted into the plantar aponeurosis in some of the lower animals: in man it is an accessory to the Gastrocnemius.

Deep Group (fig. 638)

Popliteus.

Flexor hallucis longus.

Flexor digitorum longus.

Tibialis posterior.

The **deep transverse fascia** of the leg is a septum between the superficial and deep muscles of the back of the leg. At the sides it is connected to the medial margin of the tibia and the posterior border of the fibula. Above, where it is thick and dense, it is attached to the soleal ridge of the tibia and to the fibula, below and medial to the origin of the Soleus. Between these two attachments it is continuous with the fascia covering the Popliteus and receives an expansion from the tendon of the Semimembranosus; it is thin in the middle of the leg; but below, where it covers the tendons passing behind the malleoli, it is thick, and continuous with the flexor retinaculum and the superior peroneal retinaculum (p. 685).

The **Popliteus** (fig. 638) is a flat, triangular muscle, which forms the floor of the lower part of the popliteal fossa. The lateral, or principal part of the muscle arises by a strong tendon, about 2.5 cm. long, from a depression at the anterior part of the groove on the lateral condyle of the femur, and its medial fibres take origin from the arcuate popliteal ligament (p. 522) where it blends with the fibrous capsule over the lateral meniscus and from the outer margin of the latter. It is inserted into the medial two-thirds of the triangular area above the soleal line on the posterior surface of the shaft of the tibia, and into the tendinous expansion which covers the muscle.

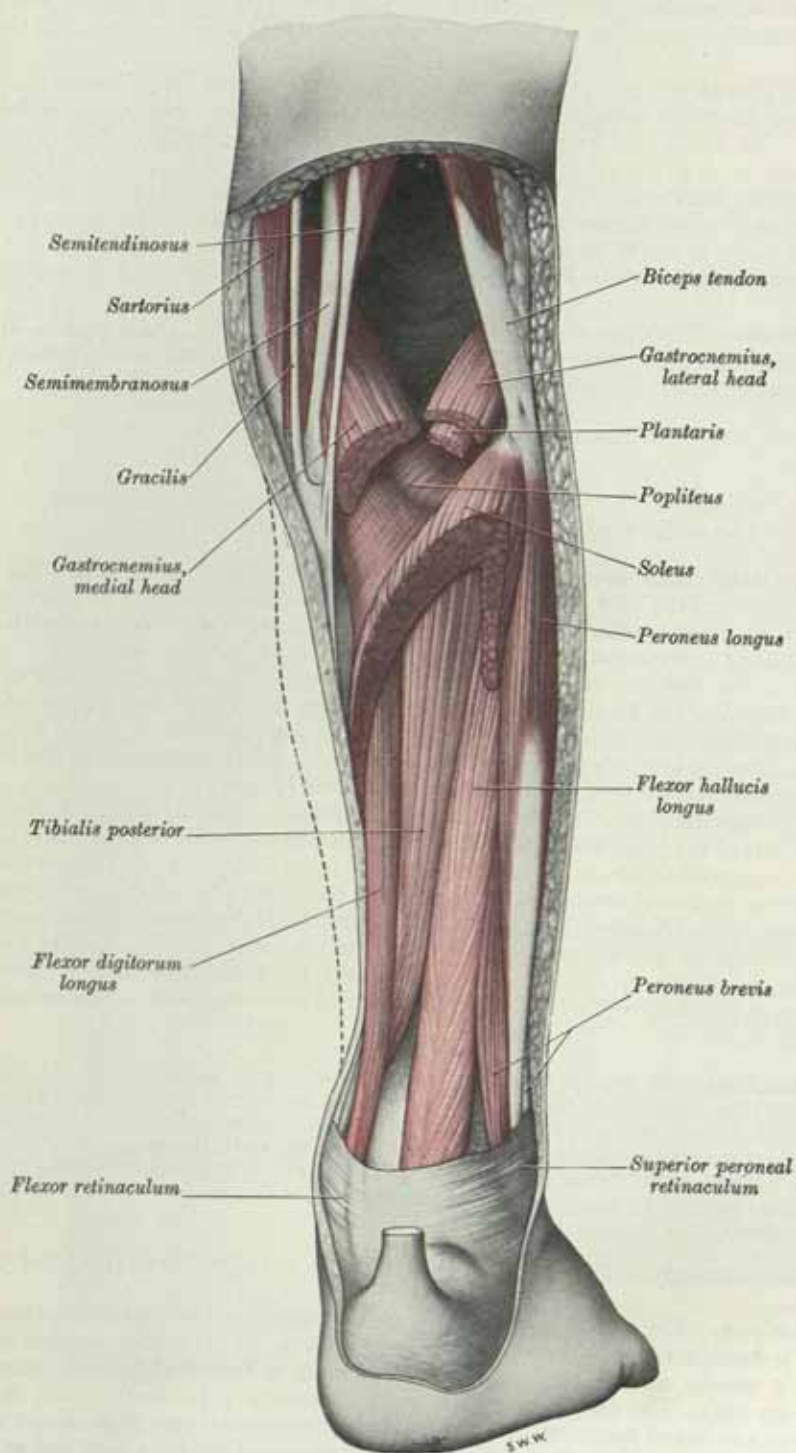
Relations.—Its tendon of origin is intracapsular and is covered by the fibular collateral ligament of the knee, and the tendon of the Biceps femoris (fig. 542). Invested on its deep surface by the synovial membrane, it grooves the posterior border of the lateral meniscus and the adjoining part of the tibia, and emerges from under cover of the posterior band of the arcuate ligament (fig. 537). On the floor of the popliteal fossa it is covered by a strong layer of fascia which is derived for the most part from the tendon of the Semimembranosus.

Nerve-supply.—The Popliteus is supplied by the tibial nerve (L. 4 and 5 and S. 1).

Actions.—The Popliteus rotates the tibia medially on the femur, or, when the tibia is fixed, rotates the femur laterally on the tibia. It is usually regarded as the muscle which 'unlocks' the joint at the beginning of flexion of the fully extended knee (p. 528). Through its connexion with the arcuate popliteal ligament, fibrous capsule and lateral meniscus, it is able to draw the posterior part of the latter backwards during lateral rotation of the femur and flexion of the knee joint and so protects the meniscus from being crushed between the femur and the tibia during these movements.

The **Flexor hallucis longus** (figs. 636, 638) is situated on the fibular side of the leg. It arises from the inferior two-thirds of the posterior surface of the shaft of the

FIG. 638.—The right posterior crural muscles. Deep group.
The subject was a child, aged 8 years.



fibula, with the exception of about 2.5 cm. at its lowest part; from the lower part of the posterior surface of the interosseous membrane; from the posterior crural intermuscular septum, and from the fascia covering the Tibialis posterior, which it overlaps to a considerable extent. The fibres pass obliquely downwards, and end in a tendon which occupies nearly the whole length of the posterior surface of the muscle. This tendon lies in a groove which crosses the posterior surface of the lower end of the tibia, the posterior surface of the talus, and the under surface of the sustentaculum talare of the calcaneus (figs. 639, 640). In the sole of the foot it runs forwards between the two heads of the Flexor hallucis brevis, and is inserted into the plantar surface of the base of the distal phalanx of the great toe. The grooves on the talus and calcaneus which contain the tendon of the muscle are converted by fibrous bands into a canal, which is lined by a synovial sheath. As the tendon passes forwards in the sole of the foot, it is situated above, and crosses from the lateral to the medial side of the tendon of the Flexor digitorum longus, to which it is connected by a fibrous slip. This slip varies considerably in size; it is usually distributed to the tendons for the second and third toes, but is sometimes restricted to that for the second, and occasionally is distributed to the tendon for the fourth toe, in addition.

Relations.—The *superficial surface* of the muscle is in relation with the Soleus and tendo calcaneus, from which it is separated by the deep transverse fascia; its *deep surface*, with the fibula, Tibialis posterior, the peroneal vessels, the lower part of the interosseous membrane, and the talocrural joint; its *lateral border*, with the Peronei; its *medial border*, with the Tibialis posterior, posterior tibial vessels and tibial nerve.

Nerve-supply.—The Flexor hallucis longus is supplied by the tibial nerve (L. 5 and S. 1 and 2).

The **Flexor digitorum longus** (fig. 638) is situated on the tibial side of the leg. Its upper part is thin and pointed, but the muscle gradually increases in size as it descends. It arises from the posterior surface of the shaft of the tibia, medial to the tibial origin of the Tibialis posterior; this origin extends from just below the soleal line to within 7 cm. or 8 cm. of the lower extremity of the bone; it also arises from the fascia covering the Tibialis posterior. The fibres end in a tendon which runs nearly the whole length of the posterior surface of the muscle. This tendon gradually crosses the Tibialis posterior and passes behind the medial malleolus, in a groove common to it and the Tibialis posterior, but separated from the latter by a fibrous septum; each tendon being contained in a special compartment lined by a separate synovial sheath. It passes obliquely forwards and laterally, in contact with the medial side of the sustentaculum talare (fig. 639), deep to the flexor retinaculum, and enters the sole of the foot (fig. 646), where it crosses below (i.e. superficial to) the tendon of the Flexor hallucis longus, and receives from it a strong slip. It then expands and is joined by the Flexor digitorum accessorius and finally divides into four tendons, which are inserted into the plantar surfaces of the bases of the distal phalanges of the second, third, fourth, and fifth toes, each tendon passing through an opening in the corresponding tendon of the Flexor digitorum brevis opposite the base of the proximal phalanx.

Relations.—In the leg its *superficial surface* is in relation with the deep transverse fascia, which separates it from the Soleus, and, distally, with the posterior tibial vessels and tibial nerve; its *deep surface*, with the tibia and Tibialis posterior. In the foot it is covered by the Abductor hallucis and Flexor digitorum brevis, and crosses superficial to the Flexor hallucis longus.

Nerve-supply.—The Flexor digitorum longus is supplied by the tibial nerve (L. 5, S. 1 and 2).

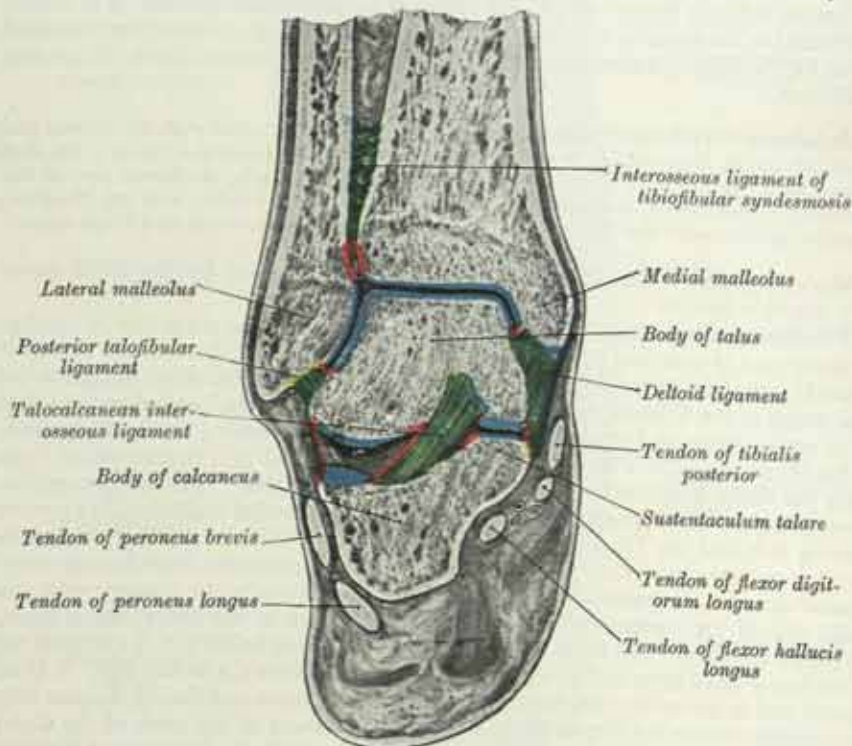
Actions.—When the foot is off the ground, both the preceding muscles flex the phalanges of the toes, acting primarily on the distal phalanges. In continued action, they assist in plantar-flexion of the foot.

When the foot is on the ground and under load, these muscles, acting synergically with the small muscles of the foot and—in the case of the Flexor digitorum longus—especially with the Lumbricales and Interossei (p. 690), maintain the pads of the toes in firm contact with the ground, enlarging the weight-bearing area and helping to stabilise the heads of the metatarsal bones, which form the fulcrum on which the body is propelled forwards.

Both the *Flexor hallucis longus* and the *Flexor digitorum longus* play important parts in maintaining the longitudinal arch of the foot (p. 544).

The **Tibialis posterior** (figs. 633, 638) takes origin between the *Flexor hallucis longus* and *Flexor digitorum longus*, and is overlapped by both muscles, but especially by the *Flexor hallucis longus*; it is the deepest muscle on the back of the leg. It begins above by two pointed processes, separated by an angular interval through which the anterior tibial vessels pass to the front of the leg. It arises from the posterior surface of the crural interosseous membrane, with the exception of its lowest part; from the lateral portion of the posterior surface of the shaft of the tibia, between the commencement of the soleal line above and the junction of the middle with the lower one-third of the shaft below; and from the upper two-thirds of the medial part of the posterior surface of the fibula; some fibres also arise from

FIG. 639.—A coronal section through the left talocrural, talocalcaneal and subtalar joints.



the deep transverse fascia, and from the intermuscular septa separating it from the adjacent muscles. In the lower one-fourth of the leg its tendon passes in front of (i.e. deep to) that of the *Flexor digitorum longus* and lies with it in a groove behind the medial malleolus, but enclosed in a separate sheath; it next passes deep to the flexor retinaculum (p. 684) and superficial to the deltoid ligament (fig. 639) into the foot, and then below the plantar calcaneonavicular ligament, where it contains a sesamoid fibrocartilage. It is inserted into the tuberosity of the navicular bone, and gives off fibrous slips, one of which passes backwards and is attached to the sustentaculum talare of the calcaneus, while others pass forwards and laterally and are fixed to the three cuneiform bones, the cuboid bone, and the bases of the second, third, fourth and, sometimes, fifth metatarsal bones (fig. 458).

Relations.—The superficial surface of the muscle is in relation with the Soleus from which it is separated by the deep transverse fascia, the *Flexor digitorum longus*, the *Flexor hallucis longus*, the posterior tibial vessels, tibial nerve, and the peroneal vessels; its deep surface with the interosseous membrane, the tibia, fibula and tibial joint.

Nerve-supply.—The *Tibialis posterior* is supplied by the tibial nerve (L. 4 and 5).

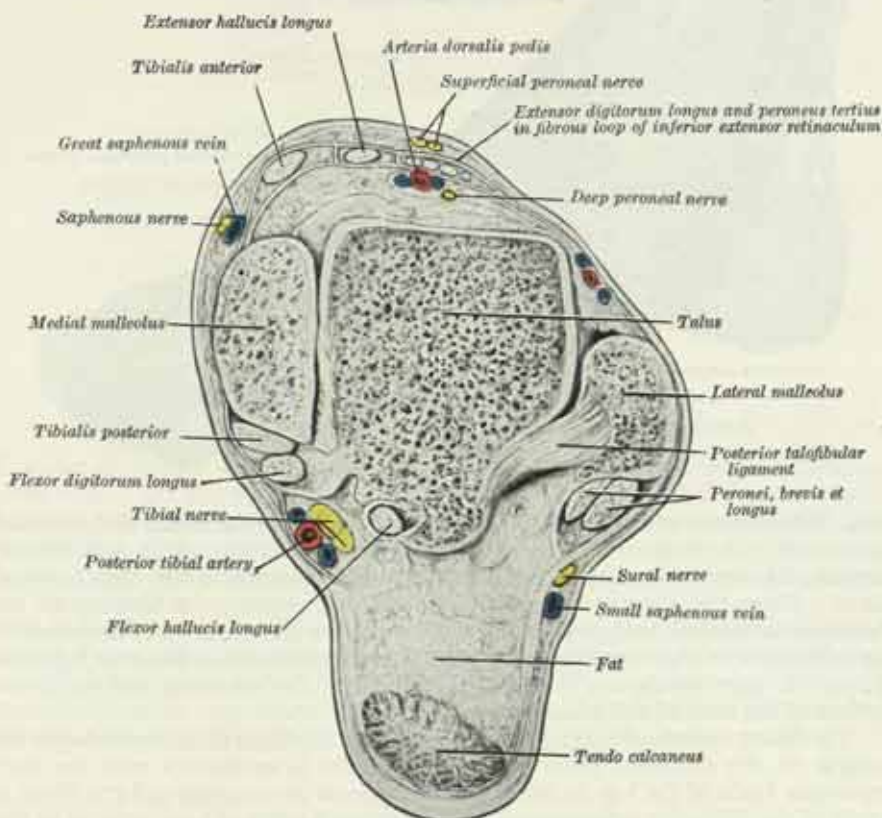
Actions.—The Tibialis posterior is the principal invertor of the foot. Through its additional slips of insertion into the cuneiform bones and the bases of the metatarsals it is capable of accentuating the longitudinal arch of the foot, and it is the most important factor in the maintenance of that arch (p. 544), when the foot is bearing weight. The attention of the student has already been drawn to the functional importance of the maintenance of the arches of the foot (pp. 544-545).

When the body is supported on one leg, the Tibialis posterior, acting from below, assists in maintaining the balance by resisting any tendency to overbalance to the lateral side.* It must be remembered, however, that the maintenance of the balance in this position calls into play a very large number of muscle groups and particularly groups acting on the hip joint and others acting on the vertebral column.

THE FASCIA ROUND THE ANKLE

As the tendons of the muscles of the leg cross the talocrural joint on their way to the foot, they are bound down by localised thickenings in the deep fascia which constitute retinacular bands comparable, both in mode of formation and in function, to the flexor and extensor retinacula of the wrist (p. 640). They comprise the

FIG. 640.—Transverse section through the lower part of the talocrural joint.



superior and inferior extensor retinacula, the flexor retinaculum, and the superior and inferior peroneal retinacula.

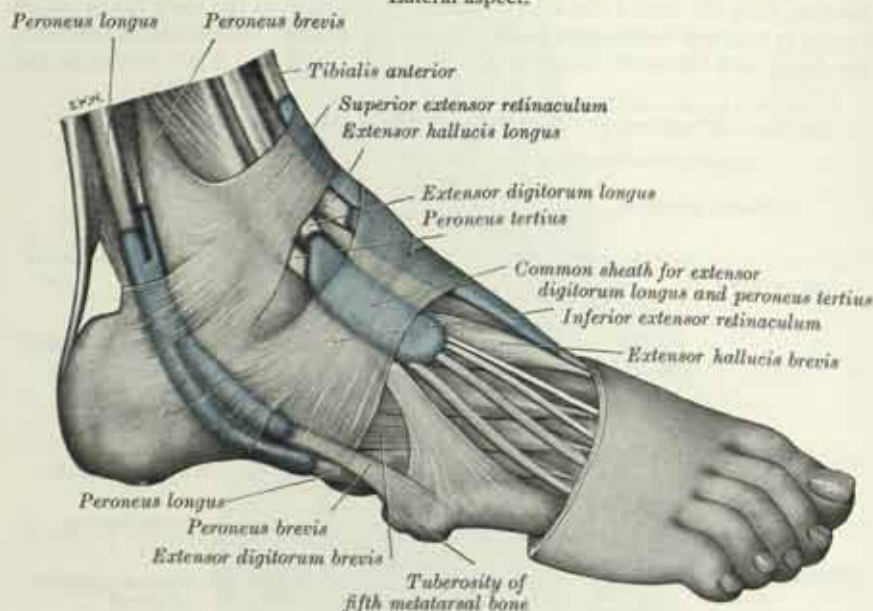
The **superior extensor retinaculum** (figs. 634, 641) binds down the tendons of the Tibialis anterior, Extensor hallucis longus, Extensor digitorum longus and Peroneus tertius, as they descend immediately above the front of the talocrural joint; the anterior tibial vessels and the deep peroneal nerve also pass under cover of it. It is attached laterally to the lower end of the anterior border of the fibula, and medially

* F. Wood Jones, *Structure and Function as seen in the Foot*, London, 1944.

to the anterior border of the tibia; above, it is continuous with the deep fascia of the leg. Of the tendons concerned only the Tibialis anterior has a synovial sheath in this situation (fig. 641).

The **inferior extensor retinaculum** (figs. 634, 641) is a Y-shaped band placed in front of the talocrural joint. The stem of the Y is attached to the upper surface of the calcaneus, in front of the sulcus calcanei, and passes medially, forming a strong loop which encloses the tendons of the Peroneus tertius and the Extensor digitorum longus (fig. 640). From the extremity of this loop two diverging bands pass medially to complete the Y. The *upper band* consists of two distinct lamellæ. The deep lamella passes behind the tendons of the Extensor hallucis longus and the Tibialis anterior, but in front of the anterior tibial vessels and deep peroneal nerve, to reach the tibial malleolus. The superficial lamella crosses in front of the tendon of the Extensor hallucis longus and is then firmly connected to the deep lamella; it may or may not be continued in front of the tendon of the Tibialis anterior to reach the

FIG. 641.—The synovial sheaths of the tendons round the right ankle. Lateral aspect.



tibia. The *lower band* extends downwards and medially to be attached to the plantar aponeurosis; it crosses the tendons of the Extensor hallucis longus and Tibialis anterior, the arteria dorsalis pedis and the terminal branches of the deep peroneal nerve. From the deep surface of the loop which encloses the tendons of the Peroneus tertius and the Extensor digitorum longus, a distinct band of fibres passes medially between the constituent layers of the interosseous talocalcaneal ligament (p. 536) to gain attachment to the upper surface of the calcaneus and the under surface of the neck of the talus.*

The **flexor retinaculum** (fig. 635) extends from the tibial malleolus above to the margin of the calcaneus below; its upper border is continuous with the deep transverse fascia of the leg, its lower with the plantar aponeurosis and the fibres of origin of the Abductor hallucis muscle. It converts a series of bony grooves in this situation into canals for the passage of the tendons of the flexor muscles into the sole of the foot, and also affords protection to the posterior tibial vessels and tibial nerve as they enter the sole of the foot. From the medial to the lateral side these structures lie in the following order: tendon of the Tibialis posterior, tendon of the Flexor digitorum longus, posterior tibial vessels, tibial nerve, and tendon of the Flexor hallucis longus (fig. 640).

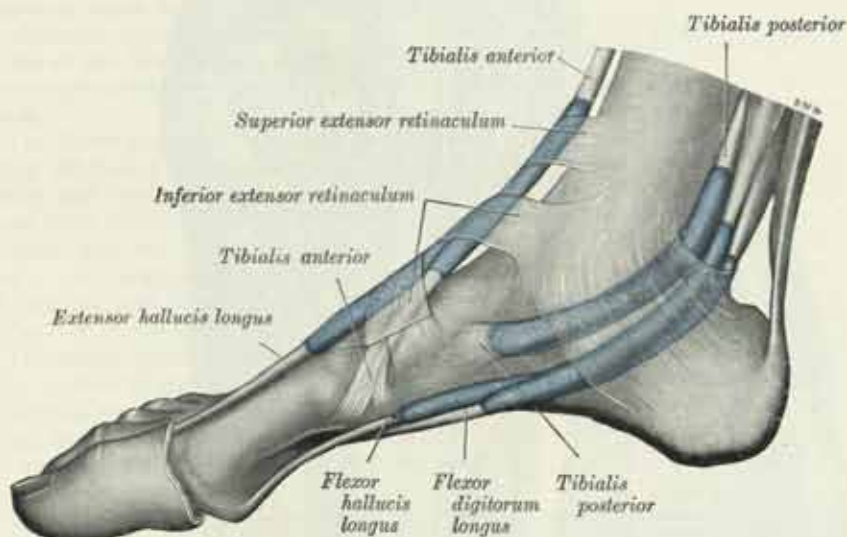
The **peroneal retinacula** are fibrous bands which retain the tendons of the Peroneus longus and brevis in position as they cross the lateral side of the ankle.

* E. Barclay Smith, *J. Anat., Lond.*, 30, 1896. T. T. Stamm, *Ibid.*, 66, 1931.

The *superior retinaculum* (fig. 638) extends from the back of the lateral malleolus to the deep transverse fascia of the leg and the lateral surface of the calcaneus. The *inferior retinaculum* is continuous in front with the inferior extensor retinaculum; behind it is attached to the lateral surface of the calcaneus; some of its fibres are fixed on the peroneal trochlea of the calcaneus, forming a septum between the tendons of the *Peroneus longus* and *brevis*.

The synovial sheaths of the tendons round the ankle.—The tendons crossing the talocrural joint are enclosed in synovial sheaths. On the *front* of the ankle (fig. 641) the sheath for the *Tibialis anterior* extends from the upper margin of the upper extensor retinaculum to the interval between the diverging limbs of the lower retinaculum (fig. 642); the sheath for the *Extensor digitorum longus* and *Peroneus tertius* and that for the *Extensor hallucis longus* reach upwards to just above the level of the malleoli, the former being the higher. The sheath of the *Extensor hallucis longus* is prolonged on to the base of the first metatarsal bone, while that of the

FIG. 642.—The synovial sheaths of the tendons round the right ankle. Medial aspect.



Extensor digitorum longus reaches only to the level of the base of the fifth metatarsal bone. On the *medial side* of the ankle (fig. 642) the sheath for the *Tibialis posterior* extends for about 4 cm. above the malleolus; below, it ends just short of the insertion of the tendon into the tuberosity of the navicular bone. The sheath for the *Flexor hallucis longus* reaches up to the level of the malleolus, while that for the *Flexor digitorum longus* goes slightly higher; the former is continued to the base of the first metatarsal bone, but the latter ends opposite the navicular bone. On the *lateral side* of the ankle (fig. 641) a sheath, the upper part of which is single and the lower part double, encloses the *Peroneus longus* and *brevis*. It extends upwards for about 4 cm. above the tip of the malleolus, and downwards and forwards for about the same distance.

IV. THE MUSCLES OF THE FOOT

1. THE DORSAL MUSCLE OF THE FOOT

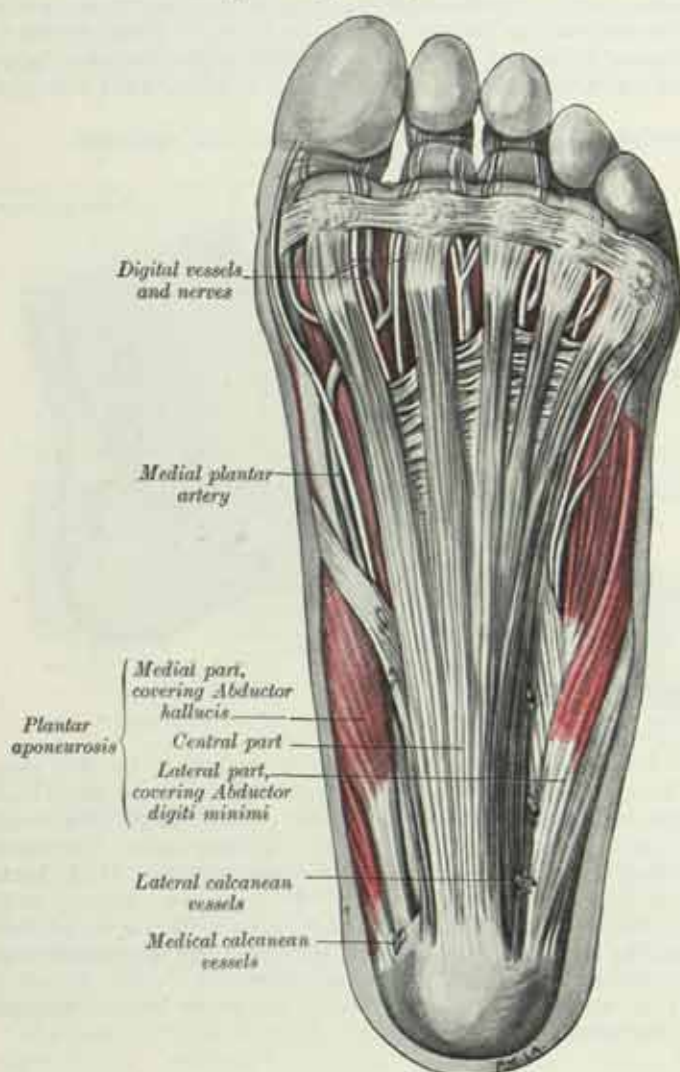
Extensor digitorum brevis.

The **fascia** on the dorsum of the foot (*fascia dorsalis pedis*) is a thin, membranous layer, continuous above with the inferior extensor retinaculum; at the sides of the foot it blends with the plantar aponeurosis; anteriorly it ensheathes the tendons on the dorsum of the foot.

The ***Extensor digitorum brevis*** (figs. 634, 641) is a thin muscle, which arises from the fore part of the upper and lateral surface of the calcaneus, in front of the

groove for the *Peroneus brevis*; from the interosseous talocalcaneal ligament, and the stem of the inferior extensor retinaculum. It passes obliquely forwards and medially across the dorsum of the foot, and ends in four tendons. The medial part of the muscle is usually a more or less distinct slip ending in a tendon which crosses the *dorsalis pedis* artery and is inserted into the dorsal surface of the base of the proximal phalanx of the great toe; it is termed the *Extensor hallucis brevis*. The other three tendons are inserted into the lateral sides of the tendons of the *Extensor digitorum longus* of the second, third and fourth toes.

FIG. 643.—The plantar aponeurosis of the left foot.



Nerve-supply.—The *Extensor digitorum brevis* is supplied by the lateral terminal branch of the deep peroneal nerve (L. 5 and S. 1).

Actions.—The *Extensor digitorum brevis* extends the phalanges of the four toes into which it is inserted, but, in the great toe, acts only on the first phalanx.

2. THE PLANTAR MUSCLES OF THE FOOT

The **plantar aponeurosis** (fig. 643) is of great strength, and consists of white fibres disposed, for the most part, longitudinally: it is divided into central, lateral, and medial portions.

The *central portion* is the thickest: it is narrow behind, and attached to the medial tubercle of the calcaneus proximal to the origin of the Flexor digitorum brevis; it becomes broader and thinner distally, and divides near the heads of the metatarsal bones into five processes, one for each toe. Each of these processes splits opposite the metatarsophalangeal joint into a superficial and a deep stratum. The superficial stratum is attached to the skin of the transverse sulcus which separates the toes from the sole. The deep stratum divides into two slips which embrace the sides of the flexor tendons of the toes, and blend with the fibrous sheaths of these tendons and with the deep transverse metatarsal ligaments, thus forming a series of arches through which the tendons of the short and long flexors pass to the toes. Through the intervals between the five processes the digital vessels and nerves and the tendons of the Lumbrical muscles are transmitted. At the point of division of the aponeurosis numerous transverse fasciculi bind the processes together, and connect them with the skin. The central portion of the plantar aponeurosis is continuous with the lateral and medial portions, and sends upwards, at the lines of junction, two vertical intermuscular septa, which separate the intermediate from the lateral and medial groups of plantar muscles; from these vertical septa thinner transverse septa are derived which separate the different layers of muscles. The deep surface of the central part of the aponeurosis gives origin proximally to the Flexor digitorum brevis.

FIG. 644.—The plantar muscles of the right foot. First layer.

The *lateral portion* covers the under surface of the Abductor digiti minimi; it is thin distally and thick proximally, where it forms a strong band between the lateral tubercle of the calcaneus and the base of the fifth metatarsal bone; it is continuous medially with the central portion, and laterally with the fascia on the dorsum of the foot.

The *medial portion* is thin, and covers the under surface of the Abductor hallucis; it is continuous proximally with the flexor retinaculum, medially with the fascia dorsalis pedis, and laterally with the central portion of the plantar aponeurosis.

The muscles in the plantar region of the foot may be divided into medial, lateral and intermediate groups; but for descriptive purposes it is more convenient to group them in four layers, as met with in the course of dissection.

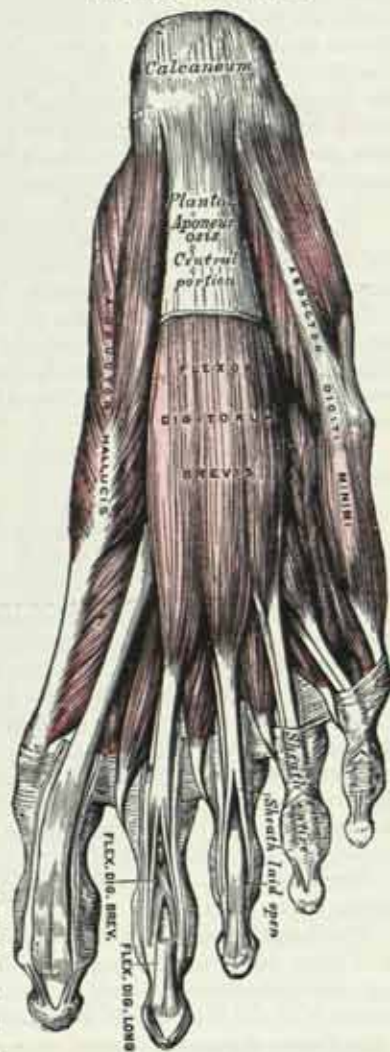
The First Layer (fig. 644)

Abductor hallucis. Flexor digitorum brevis.
Abductor digiti minimi.

All the muscles of this layer extend from the tubercles of the calcaneus to the toes, and therefore, together with the plantar aponeurosis, play a subsidiary part in maintaining the longitudinal arches of the foot.

The **Abductor hallucis** (fig. 644) lies along the medial border of the foot and covers the origins of the plantar vessels and nerves. It arises from the medial tubercle of the calcaneus, the flexor retinaculum, the plantar aponeurosis, and the intermuscular septum between it and the Flexor digitorum brevis. The fibres end in a tendon which is inserted,

together with the medial tendon of the Flexor hallucis brevis, into the medial side of the base of the proximal phalanx of the great toe.



Nerve-supply.—The Abductor hallucis is supplied by the medial plantar nerve (L. 5 and S. 1).

The **Flexor digitorum brevis** (fig. 644) lies immediately under cover of the central part of the plantar aponeurosis. Its deep surface is separated from the lateral plantar vessels and nerves by a thin layer of fascia. It arises by a narrow tendon from the medial tubercle of the calcaneus, from the central part of the plantar aponeurosis, and from the intermuscular septa between it and the adjacent muscles. It divides into four tendons, one for each of the four lesser toes. Opposite the bases of the proximal phalanges, each tendon divides into two slips, to allow of the passage of the corresponding tendon of the Flexor digitorum longus; the two slips then unite, partially decussate, and form a grooved channel for the reception of the tendon of the Flexor digitorum longus. The tendon divides again and is inserted into the sides of the middle phalanx about its middle. The mode of division of the tendons of the Flexor digitorum brevis, and of their insertion into the phalanges, is identical with that of the tendons of the Flexor digitorum superficialis in the hand.

Nerve-supply.—The Flexor digitorum brevis is supplied by the medial plantar nerve (L. 5 and S. 1 and 2).

The **fibrous sheaths of the flexor tendons** (fig. 644).—The terminal portions of the tendons of the long and short flexor muscles are contained in osseoponeurotic canals similar in their arrangement to those in the fingers. These canals are bounded above by the phalanges, and below by fibrous bands, the *digital fibrous sheaths*, which arch across the tendons, and are attached on either side to the margins of the phalanges. Opposite the shafts of the proximal and middle phalanges the fibrous bands are strong, and the fibres are transverse (*anular part*); but opposite the joints they are much thinner, and the fibres are directed obliquely (*cruciform part*). Each canal contains a synovial sheath, which is reflected on the contained tendons; within this sheath *vincula tendinum* are arranged similarly to those of the fingers (p. 630).

The **Abductor digiti minimi** (fig. 644) lies along the lateral border of the foot, and its medial margin is in relation with the lateral plantar vessels and nerve. It arises from the lateral and medial tubercles of the calcaneus, from the plantar surface of the bone between the processes, from the plantar aponeurosis, and from the intermuscular septum between it and the Flexor digitorum brevis. Its tendon glides over a smooth groove on the plantar surface of the base of the fifth metatarsal bone and is inserted, with the Flexor digiti minimi brevis, into the lateral side of the base of the proximal phalanx of the fifth toe.

Nerve-supply.—The Abductor digiti minimi is supplied by the lateral plantar nerve (S. 1 and 2).

The Second Layer (figs. 645, 646)

Flexor digitorum accessorius.

Lumbricales.

The **Flexor digitorum accessorius** (fig. 646) arises by two heads which are separated by the long plantar ligament: the medial, and larger, head is muscular, and is attached to the medial concave surface of the calcaneus below the groove for the tendon of the Flexor hallucis longus; the lateral head, flat and tendinous, arises from the calcaneus in front of the lateral tubercle and from the long plantar ligament. The two portions join at an acute angle, and end in a flattened band which is inserted into the superior surface and lateral margin of the tendon of the Flexor digitorum longus, forming a kind of groove in which the tendon is lodged. It usually sends slips to those tendons of the Flexor digitorum longus which pass to the second, third and fourth toes.

Nerve-supply.—The Flexor digitorum accessorius is supplied by the lateral plantar nerve (S. 1).

The **Lumbricales** (fig. 646) are four small muscles, accessory to the tendons of the Flexor digitorum longus, and numbered from the medial side of the foot; they arise from these tendons, as far back as their angles of separation, and, with the exception of the first, which arises only from the medial border of the first tendon of the Flexor digitorum longus, each springs from two tendons. The muscles end in tendons which pass distally on the medial sides of the four lesser toes, and are inserted into the dorsal digital expansions on the dorsal surfaces of the proximal phalanges.

Nerve-supply.—The first Lumbrical is supplied by the medial plantar nerve (L. 5 and S. 1); the others by the deep branch of the lateral plantar nerve (S. 1 and 2).

The Third Layer (figs. 645, 647)

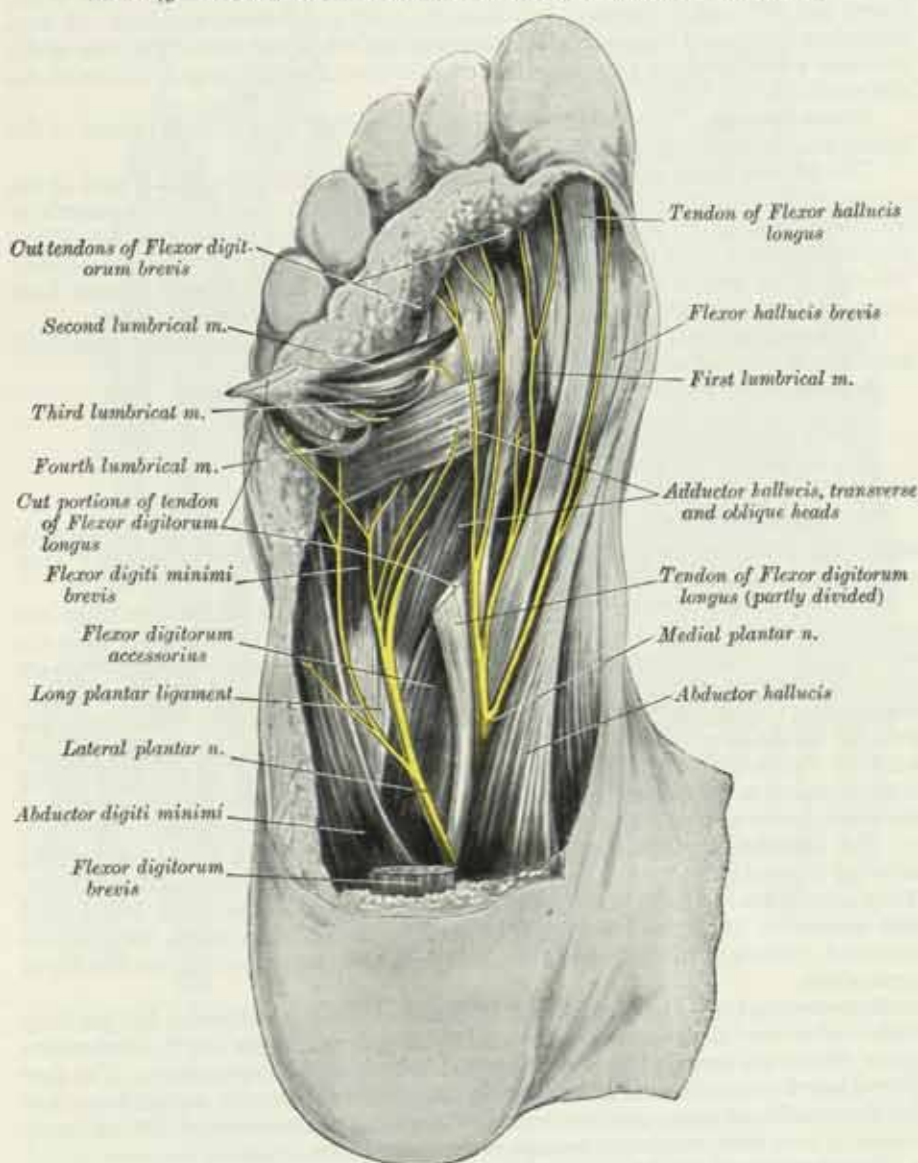
Flexor hallucis brevis.

Adductor hallucis.

Flexor digiti minimi brevis.

The **Flexor hallucis brevis** (fig. 647) arises by a pointed, tendinous process from the medial part of the plantar surface of the cuboid bone, behind the groove

FIG. 645.—The muscles of the sole of the foot and their nerves of supply.



Most of the Flexor digitorum brevis has been removed. The Flexor digitorum longus has been divided partially, and its distal end has been turned forwards together with the second, third and fourth Lumbrical muscles.

for the Peroneus longus tendon, from the contiguous portion of the lateral cuneiform bone, and from the part of the tendon of the Tibialis posterior which is attached to that bone. It divides into a medial and a lateral portion, and the tendons of these

are inserted into the corresponding sides of the base of the proximal phalanx of the great toe, a sesamoid bone being present in each tendon at its insertion. The medial portion is blended with the Abductor hallucis previous to its insertion; the lateral, with the Adductor hallucis.

Nerve-supply.—The Flexor hallucis brevis is supplied by the medial plantar nerve (L. 5 and S. 1).

The **Adductor hallucis** (fig. 647) arises by two heads—oblique and transverse. The *oblique head* springs from the bases of the second, third and fourth metatarsal bones, and from the sheath of the tendon of the Peroneus longus, and is inserted, together with the lateral portion of the Flexor hallucis brevis, into the lateral side of the base of the proximal phalanx of the great toe. The *transverse head*, a narrow, flat fasciculus, arises from the plantar metatarsophalangeal ligaments of the third, fourth and fifth toes (sometimes only from the third and fourth), and from the deep transverse metatarsal ligaments. It is inserted into the lateral side of the base of the proximal phalanx of the great toe, its tendon of insertion blending with that of the oblique head.

Nerve-supply.—The Adductor hallucis is supplied by the deep branch of the lateral plantar nerve (S. 1 and 2).

The **Flexor digiti minimi brevis** (fig. 647) arises from the medial part of the plantar surface of the base of the fifth metatarsal bone, and from the sheath of the Peroneus longus; its tendon is inserted into the lateral side of the base of the proximal phalanx of the fifth toe. Occasionally a few of the deeper fibres are inserted into the lateral part of the distal one-half of the fifth metatarsal bone: these have sometimes been described as a distinct muscle—the *Opponens digiti minimi*.

Nerve-supply.—The Flexor digiti minimi brevis is supplied by the superficial branch of the lateral plantar nerve (S. 1 and 2).

Action.—The Flexor digiti minimi brevis flexes the little toe.

The Fourth Layer

Interossei.

The **Interossei** in the foot are similar to those in the hand, but are grouped on each side of the middle line of the *second* digit, instead of that of the *third*. They consist of a dorsal and a plantar set.

The **Interossei dorsales** (fig. 648), four in number, are situated between the metatarsal bones. They are bipennate muscles, each arising by two heads from the adjacent sides of the metatarsal bones between which it is placed; their tendons are inserted into the bases of the proximal phalanges, and into the dorsal digital expansions. The first is inserted into the medial side of the second toe; the other three into the lateral sides of the second, third, and fourth toes. In the angular interval between the heads of each of the three lateral muscles, one of the perforating arteries passes to the dorsum of the foot; through the space between the heads of the first muscle the terminal part of the dorsalis pedis artery enters the sole of the foot.

The **Interossei plantares** (fig. 649), three in number, lie below rather than between the metatarsal bones, and each is connected with but one metatarsal bone. They arise from the bases and medial sides of the shafts of the third, fourth, and fifth metatarsal bones, and are inserted into the medial sides of the bases of the proximal phalanges of the same toes, and into the corresponding dorsal digital expansions.

Nerve-supply.—The Dorsal and Plantar interossei are supplied by the deep branch of the lateral plantar nerve (S. 1 and 2), except those in the fourth interosseous space, which are supplied by the superficial branch of the same nerve. The first Dorsal interosseous frequently receives an extra filament from the medial branch of the deep peroneal nerve on the dorsum of the foot, and the second Dorsal interosseous a twig from the lateral branch of the same nerve.

The Actions of the Muscles of the Foot.—It is to be observed that although the muscles of this group are capable of producing the actions which are, for the most part, indicated by their names, their effective action has to be carried out when the foot is on the ground and their nominal actions are therefore subjected to certain modifications. Their principal functions would appear to be to steady the toes with which they are associated and to help to maintain the longitudinal and transverse arches of the foot through the medium of their normal tonus.

When the heel is raised from the ground in walking or running the weight is transferred to the digital pads of the toes and the heads of the metatarsal bones. Actually, when the digital pads of the toes exert full pressure on the ground, the toes are held extended at the distal interphalangeal and metatarsophalangeal joints, but are flexed at the proximal interphalangeal joints, while the great toe is slightly extended at the metatarsophalangeal joint and flexed at the interphalangeal joint. This position results from the active contraction of the flexor digitorum brevis and

FIG. 646.—The plantar muscles of the right foot. Second layer.

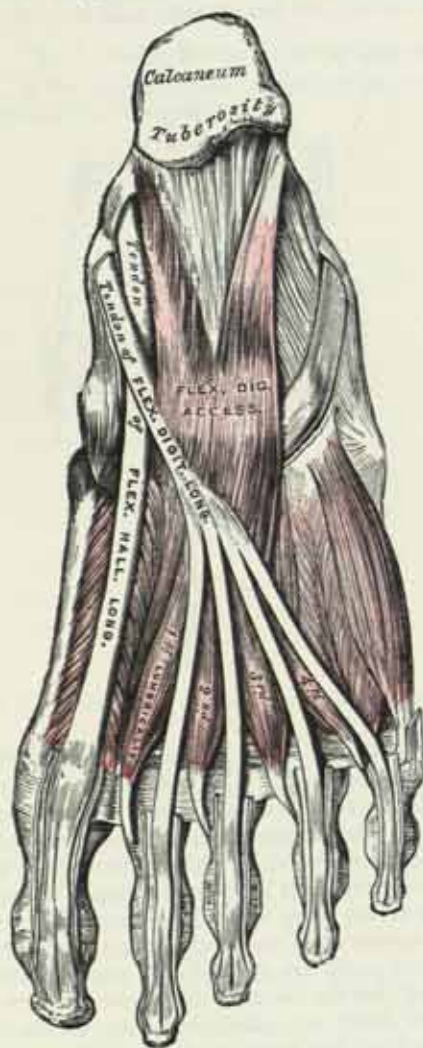


FIG. 647.—The plantar muscles of the right foot. Third layer.



the long flexors, which draw the terminal phalanges backwards and passively impose the attitude of the toes above described. An excessive degree of 'buckling' of the toes is prevented by the increased tonus of the Lumbricals and Interossei, which oppose excessive extension at the metatarsophalangeal and excessive flexion at the proximal interphalangeal joints. In the case of the great toe the Flexor hallucis brevis prevents excessive extension at the metatarsophalangeal joint.

The Movements of Locomotion.—In walking and running all the muscles of the lower limbs are actively concerned, although at any particular stage some groups may be contracting vigorously, while others may be relaxing in conformity with them. Others, again, though not engaged in helping to propel the body forwards, may exhibit an increased degree of tonus. The latter groups include those which help to preserve the balanced poise of the body (p. 665) and those which help to maintain the arches of the feet.

When walking is started from the resting erect position, the feet become slightly inverted and the longitudinal and transverse arches are accentuated (p. 545); at the same time the trunk is bent forwards slightly at the hip joints. If the first step is taken with the right foot, the right heel is elevated from the ground and the right hip and knee joints are simultaneously flexed. Active extension of the knee, accompanied by flexion of the hip joint, swings the forefoot clear of the ground, the toes being held extended and the talocrural joint becoming dorsiflexed to a slight extent. At the end of the forward swing the right heel comes into contact again with

FIG. 648.—The Interossei dorsales of the left foot. Dorsal aspect.

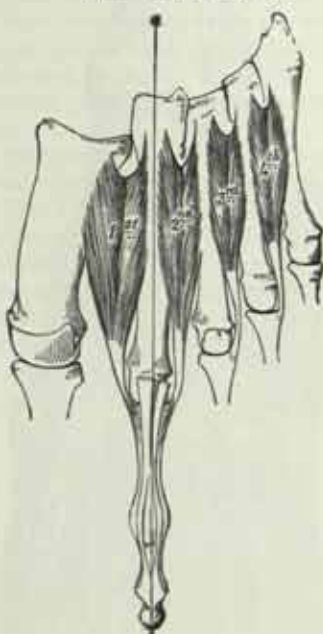
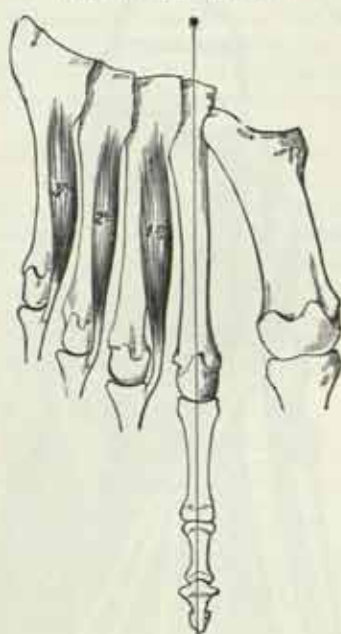


FIG. 649.—The Interossei plantares of the left foot. Plantar aspect.



the ground, the movement resembling the commencement of the back-swing of a pendulum.

As the right heel meets the ground and takes some of the body-weight, the left heel is raised and the left hip and knee joints become flexed. The weight, previously borne on the whole of the left foot, is shifted forwards to the forefoot: pressure is exerted on the ground through the pads of the toes and the heads of the metatarsal bones; and, under the propelling force of the Gastrocnemius, with the forefoot as a fulcrum, the body is levered forwards. At once the right forefoot is brought down on to the ground and, as the left forefoot is swung clear, the whole weight of the body is supported for a fraction of a second on one limb and at that stage the most important factors in maintaining its balanced poise are the Glutei, medius and minimus (p. 665). It may be noted in passing that the essential difference between the first and subsequent steps is that the latter are associated with forward propulsion. In addition to these movements there is a rotation of the segments of the lower limb around their long axes during walking. There is an internal rotation of the pelvis, femur and tibia in the swing and early stance phases with external rotation in the late stance phase.*†

The speed of walking depends, in the first instance on the degree of propulsive force used and the pressure exerted by the forefoot, but the whole series of movements can be speeded up and more muscular energy is expended as the pace is increased. The long flexors of the toes exert the necessary pressure on the ground to stabilise the fulcrum and distribute the body-weight, while the Gastrocnemius provides the main propulsive force. The Tibialis posterior and the Peroneus longus stabilise the foot and obviate any tendency to eversion or inversion.

* A. S. Levens, V. T. Inman and J. A. Blosner, *J. Bone. Jt. Surg.*, 30 A, 1948.

† J. R. Close and V. T. Inman, *Prosthetic Devices Research Project*, Institute of Engineering Research, University of California. Series II, Issue 22, 1952.

In running at speed the movements carried out are very much the same, but the heel is kept elevated from the ground by the action of the Soleus, and the weight is borne alternately on the right and left forefeet. The momentum developed is so great that, once in each pace, both feet are off the ground at the same time. The action of the Gastrocnemius is reinforced by the Quadriceps, which, by powerfully extending the knee, increases the thrust of the forefoot against the ground.

Analysis of slow motion photographs of soldiers marching * has revealed the fact that at the instant when the whole weight is taken by one foot, the Quadriceps of that side contracts momentarily, presumably to oppose the tendency of the knee joint to flex under the strain. It then relaxes, but contracts again almost immediately, this time, apparently, to assist in forward propulsion.†

* St. J. Dudley Buxton. (*Personal communication.*)

† For further details on locomotion see A. Steindler, *Kinesiology of the Human Body*, Springfield, Illinois, 1955.

ANGIOLOGY

THE vascular system is divided for descriptive purposes into (a) the *blood-vascular system*, comprising the heart and blood-vessels through which the blood circulates; and (b) the *lymphatic system*, consisting of lymphatic nodes and vessels, through which a colourless fluid, termed the lymph, circulates.* The two systems communicate with each other and are intimately associated developmentally.

The heart is a hollow, muscular organ situated within the thorax. Its contraction sends the blood to all parts of the body through a complicated series of tubes, termed *arteries*. The arteries ramify extensively in their course throughout the body, and end in minute vessels, called *arterioles*, which open into a close-meshed network of microscopic vessels, named *capillaries*. After the blood has passed through the capillaries it is collected into a series of minute vessels, called *venules*, which join with one another to form *veins*: the veins unite with one another, and ultimately two large venous trunks, named the superior and inferior *venæ cavæ*, are formed which return the blood to the heart. While the blood is passing through the capillaries a transudation of certain of its fluid elements takes place into the tissue-spaces. In proportions which vary according to the metabolic conditions, this fluid is taken up partly by the capillaries by a process of reabsorption, and partly by the lymph vessels, which return it to the large veins at the root of the neck.

The heart is divided into four chambers, of which two are receiving and two are distributing chambers. The right and left *atria* receive the blood from the great veins and expel it into the right and left *ventricles*. From the ventricles the blood is pumped into the arterial system and carried to the various organs of the body. Although each atrium communicates freely with the corresponding ventricle, the right and left chambers of the heart are separated from one another by partitions or *septa*, and they do not communicate with one another after birth in normal subjects. The superior and the inferior *venæ cavæ* bring to the right atrium blood which has become deoxygenated and has taken up carbon dioxide during its circulation through the tissues of the body. From the right atrium the blood passes into the right ventricle, by which it is expelled into the pulmonary trunk to be conveyed to the right and left lungs. As it circulates through the pulmonary capillaries the blood is brought into close relationship with the air in the lungs, and it gives off some of its carbon dioxide content and acquires a fresh supply of oxygen. Re-collected by the pulmonary veins the freshly oxygenated blood is returned to the left atrium of the heart and passes into the left ventricle. With each beat of the heart the left ventricle pumps its contents into a large artery termed the *aorta*, which distributes blood through its numerous branches to all the tissues and organs of the body with the exception of the lungs.

The course of the blood from the left ventricle through the body generally to the right side of the heart constitutes the greater or *systemic* circulation, while its passage from the right ventricle through the lungs to the left side of the heart is termed the lesser or *pulmonary* circulation.

It is necessary, however, to point out that the blood which circulates through the spleen, pancreas, stomach and the intestines is not returned directly from these organs to the heart, but is conveyed by the *portal vein* to the liver. In the liver this vein divides like an artery, and ultimately ends in capillary-like vessels (*sinusoids*), from which the rootlets of the *hepatic veins* arise; the hepatic veins carry the blood into the inferior vena cava, which conveys it to the right atrium. This constitutes the *portal circulation*, and it will be understood that the blood supplied to the above-named viscera passes through two sets of minute vessels before reaching the inferior vena cava: (1) the capillaries in the spleen, pancreas, stomach, etc., draining into the portal vein, and (2) the sinusoids in the liver, draining into the hepatic veins. The passage through two sets of capillaries enables the blood to take up products of digestion from the alimentary canal and to convey them to the liver cells, where sugar is stored in the form of glycogen.

* The blood and lymph are described on pp. 44-50.

It should be stated that, in addition to the normal capillaries, cross-communications exist between the arterioles and venules in the skin of the hands and feet and in other situations in the body. They are considered more fully on p. 699.

THE STRUCTURE OF THE BLOOD-VESSELS

The **arteries** (figs. 650, 651).—The structure of all arteries is not identical and a distinction may be drawn between large arteries, medium-sized arteries and arterioles.

Large arteries (fig. 650).—These vessels, such as the aorta, carotid, etc., are termed *arteries of the elastic type* because of the large proportion of elastic tissue relative to muscle in their walls. The lumen is larger relative to the thickness of the wall than it is in the smaller arteries. As in all arteries the wall comprises three coats, named from within outwards the *intima*, the *media* and the *adventitia*.

The *tunica intima* consists of a layer of endothelial cells and a layer of sub-endothelial connective tissue. The endothelial cells are flattened and oval, with their long axes in the line of the vessel. The subendothelial connective tissue comprises first, a layer of interlacing collagenous and elastic fibres with a few branched cells and some plain muscle fibres. This is succeeded by a fenestrated elastic membrane which corresponds to the internal elastic lamina of the smaller arteries, but is not sharply demarcated from the tunica media because the latter, in these larger arteries, contains a succession of similar elastic membranes.

The *tunica media* consists almost entirely of concentric, circularly disposed elastic membranes, separated from one another by fibrous tissue containing plain muscle cells.

The *tunica adventitia* is composed of fibrous tissue containing a few elastic fibres. It is relatively thin and merges imperceptibly into the surrounding connective tissue.

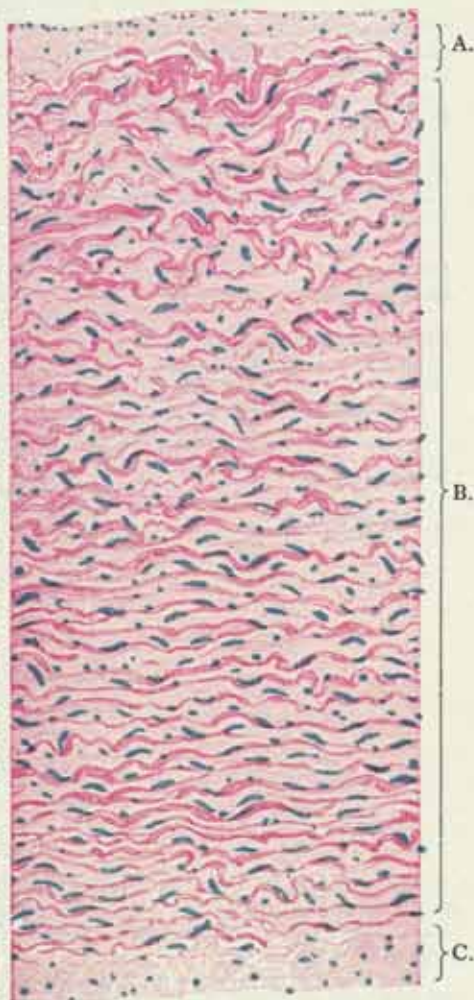
Medium-sized arteries (fig. 651). Most of the arteries belong to this group. They are sometimes called *arteries of the muscular type*.

The *tunica intima* consists of a single layer of endothelium and the *internal elastic lamina*. The latter is a fenestrated elastic membrane appearing in transverse sections as a bright refractile zone which, because of agonal contraction of the muscular media, is thrown into characteristic wavy folds. As there is less elastic tissue in the media than there is in the larger vessels, the internal elastic lamina stands out in sharp contrast.

The *tunica media* consists almost entirely of plain muscle cells, disposed circularly, separated by a few scattered elastic membranes.

The *tunica adventitia* consists of collagenous and elastic fibres which run predominantly in a longitudinal direction. The outer portion is somewhat loosely arranged, merges, imperceptibly into the surrounding areolar tissue, and so allows considerable movement between the artery and the neighbouring structures. Immediately adjacent to the plain muscle of the tunica media the adventitia contains much elastic tissue which here constitutes the *external elastic lamina*.

FIG. 650.—A portion of a transverse section of the wall of the aorta.

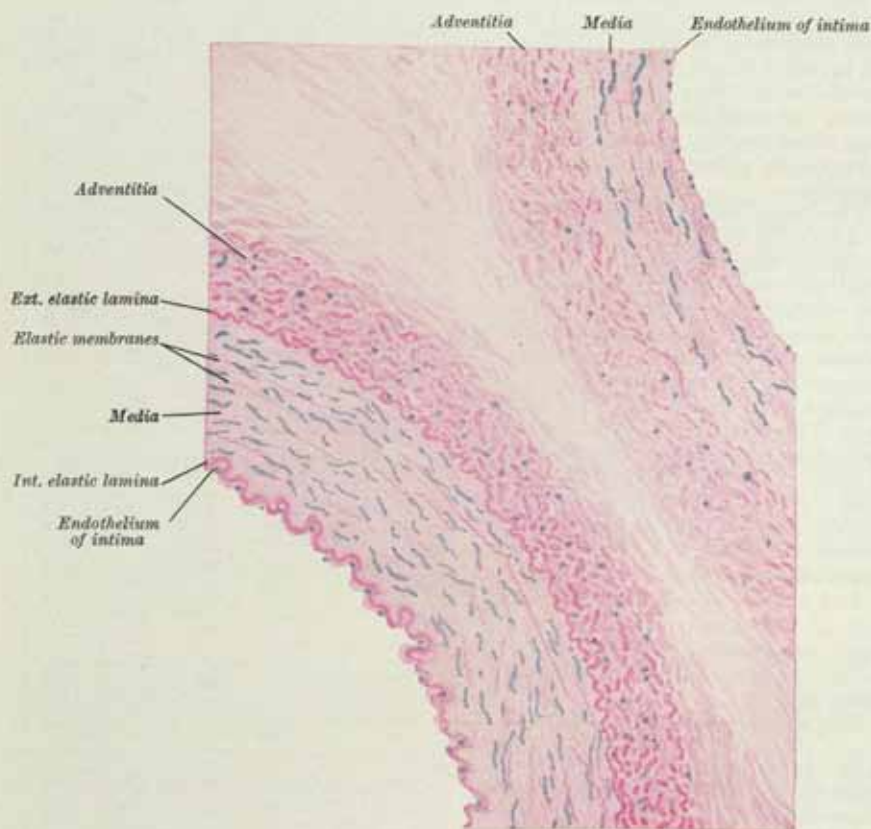


A. Intima. B. Media. C. Adventitia.

Arterioles.—These vessels differ from the medium-sized arteries in size and in the relative thickness of the three coats. The intima and media are thin, whilst the adventitia increases in relative thickness which almost equals that of the media. As the arterioles merge with the capillaries the internal elastic lamina and the tunica media become progressively thinner and finally disappear altogether; the adventitia loses its elastic tissue and is ultimately replaced by perivascular reticular connective tissue.

Some arteries have extremely thin walls in proportion to their size; this is especially the case in those situated within the cranium and vertebral canal, where the external and middle coats of the arteries are reduced in thickness.

FIG. 651.—A transverse section of parts of the walls of an adjacent artery (lower left) and vein (upper right) of medium size.



The arteries, in their distribution throughout the body, are enclosed in thin fibro-areolar sheaths. An artery is loosely connected with its sheath by delicate areolar tissue; and the sheath usually encloses the accompanying veins, and sometimes a nerve.

The larger arteries are supplied with blood-vessels. These nutrient vessels, called the *vasa vasorum*, arise from branches of the artery itself, or of a neighbouring vessel, at some considerable distance from the points at which they are distributed; they ramify in the loose areolar tissue connecting the artery with its sheath, and, after forming a dense capillary network in the adventitia, supply the outer part of the media. Minute veins return the blood from these vessels; they empty themselves into the vein or veins accompanying the artery. Lymph vessels are also present in the outer coat.

Arteries are also supplied with nerves, which form intricate plexuses upon the surfaces of the larger trunks, and run along the smaller arteries as single filaments, or bundles of filaments. Most of the nerve-fibres are non-medullated, and are derived from the sympathetic system, but some are medullated. The non-medullated fibres are mostly efferent, and end in pericellular networks in the middle coat. Some of the medullated fibres are believed to be afferent and are distributed to the outer and inner coats where they terminate in expanded and varicose endings. Lamel-

lated corpuscles (Pacinian corpuscles) are occasionally found in the outer coat of the aorta.

Evidence for the existence of vasodilator fibres is steadily accumulating and their presence in animals is undoubted. They are cholinergic * in character and come from three sources, viz. : (1) The craniosacral parasympathetic outflow in such nerves as the chorda tympani and the pelvic splanchnic nerves : (2) some of the fibres of the sympathetic outflow distributed by the same routes as the vasoconstrictor fibres : (3) collateral branches of sensory nerves which ramify on the blood vessels of the skin and which carry antidromic impulses when the sensory endings are stimulated. Recent work indicates that such fibres also exist in man.†

The largest arterial trunks receive branches direct from the sympathetic ganglia, but for the smaller arteries (brachial, femoral, etc.) the supply is carried in the peripheral nerves and comes off in a series of small branches.‡ In the splanchnic arteries perivascular plexuses extend along the whole extent of the vessels.

The capillaries.—The arterioles (excepting those of the cavernous structure of the sexual organs, of the splenic pulp, and of the placenta), subdivide into minute vessels named *capillaries* which are interposed between the arterioles and the venules, and constitute a network, the branches of which maintain the same diameter throughout. The transition from arteriole to capillary is marked by the complete disappearance of the muscular tunica media from the vessel wall.

The *diameters* of the capillaries vary in the different tissues of the body, the usual size being about $8\ \mu$ when the blood is circulating. The smallest are found in the brain and in the mucous membrane of the intestines ; the largest in the skin, and in the marrow of bone, where they may have a diameter of $20\ \mu$.

The *form* of the capillary network varies in the different tissues, the meshes being either round or elongated. Round or angular meshes are most common, and prevail where there is a dense network, as in the lungs, in most glands and mucous membranes, and in the corium. Elongated meshes occur in muscles and nerves, the long axis of the mesh running parallel with that of the muscle or nerve. Sometimes the capillaries have a looped arrangement, as in the papillae of the tongue and skin.

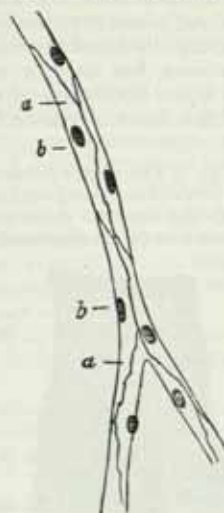
The number of the capillaries and the size of the meshes determine the degree of vascularity of a part ; the smallest meshes are found in the lungs and in the chorioid coat of the eye. As a general rule, the more active the function of the organ, the closer is its capillary net and the larger its supply of blood. Few blood-vessels are present in tendons, because of the low metabolic rate of the tissue of which they are composed. The blood-flow through the capillary network is determined and regulated by the contraction and relaxation of the corresponding arterioles.

Structure.—The wall of a capillary consists of flattened cells joined edge to edge by cement-substance, and continuous with the endothelial cells which line the arteries and veins. When stained with nitrate of silver, the material which unites the edges of the epithelial cells is displayed, thus showing the outlines of the cells (fig. 652). These cells are of large size and of an irregular polygonal or lanceolate shape, each containing an oval nucleus ; they are non-phagocytic. Alterations in the shape of the endothelial cells is probably responsible for variations in the size of the lumen of the capillaries and it is possible to alter the permeability of the vessel walls by modification of the degree to which the cells adhere one to another.

In developing capillaries, and in the capillaries of the glomeruli of the kidneys, the intestinal villi and the chorioid coat of the eye, intercellular cement cannot be demonstrated, and the cells are believed to form a syncytium.

In many situations a delicate sheath or envelope of branched, nucleated, connective tissue cells is found around the simple capillary tubes, particularly the larger ones ; and in other places, especially in the glands, the capillaries are invested with retiform connective tissue.

FIG. 652.—Capillaries from the mesentery of a guinea-pig, after treatment with a solution of nitrate of silver.



a. Cells. b. Their nuclei.

* G. L. Brown, *Physiol. Reviews*, 1937, 17.

† H. Barcroft and O. G. Edholm, *J. Physiol.*, 1945, 104.

‡ H. H. Woollard and R. Phillips, *J. Anat.*, 67, 1932-33.

Rouget (1873)* described a special variety of cell placed at intervals along certain capillaries. The cells are almost transparent and have long, branching threadlike processes which run round the circumference of the capillary tube. They are thought by most observers to be connective tissue cells and the suggestion that contraction of them alters the size of the capillary lumen is probably incorrect. 'Rouget cells' have been described (a) on some capillaries in certain situations in amphibia and (b) in some capillaries of the mammal, during certain stages of development. Indisputable evidence has not been adduced to enable one to accept their presence anywhere on a vessel less than about $10\ \mu$ in diameter, or on fully formed mammalian capillaries.†

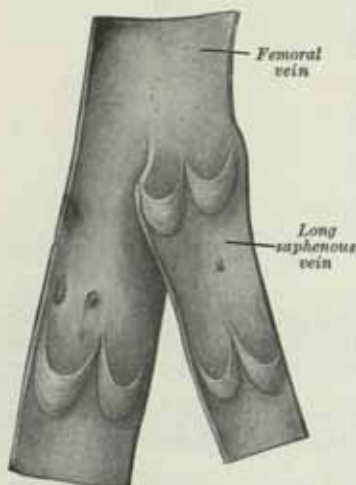
The sinusoids.—In the bone-marrow, the heart, the liver, the suprarenal and parathyroid glands, and in the carotid and coccygeal bodies, the smallest blood-vessels differ from true capillaries. They are wider, with an irregular lumen, and have little, if any, connective tissue covering their endothelial cells; these being in very close contact with the cells of the organ and including phagocytic cells of the macrophage type. Moreover, their walls may be incomplete. These vessels have been called *sinusoids* by Minot. They are formed by columns of cells or trabeculae pushing their way into a large blood-vessel or blood-space and carrying its endothelium before them; at the same time the wall of the vessel or space grows out between the columns of cells.

The veins.—The walls of the veins, like those of the arteries, are composed of three coats—internal, middle, and external; and these are, with the necessary modifications, analogous to the coats of the arteries; the internal being the endothelial the middle the muscular, and the external the connective tissue or areolar. The main difference between the veins and the arteries is in the comparative weakness of the middle coat in the former.

In the smallest veins the three coats are difficult to distinguish. The endothelium is supported on a membrane separable into two layers, the outer of which is the thicker, and consists of a delicate, nucleated membrane (*tunica adventitia*), while the inner is composed of a network of longitudinal elastic fibres (*tunica media*). In the veins next above these in size (0.4 mm. in diameter) a layer of white fibres containing a few smooth muscular fibres circularly disposed forms the middle coat, while the elastic and connective tissue elements of the outer coat are more distinctly perceptible. In the middle-sized veins (fig. 650), the endothelium is of the same character as in the arteries, but its cells are shorter and broader. It is supported by a connective tissue layer, consisting of a delicate network of branched cells, and external to this there is a layer of elastic fibres disposed in the form of a network in place of the

definite fenestrated membrane seen in arteries. This constitutes the *tunica intima*. The *tunica media* is composed of a thick layer of connective tissue with elastic fibres, intermixed, in some veins, with smooth muscular fibres arranged circularly. The white fibres are in considerable excess, and the elastic fibres are in much smaller proportion in the veins than in the arteries. The *tunica adventitia* consists, as in the arteries, of areolar tissue with longitudinal elastic fibres. In the largest veins it is very much thicker than the *tunica media*, and contains many longitudinal muscular fibres. These are most distinct in the inferior vena cava, especially at the termination of this vein in the heart, in the trunks of the hepatic veins, in all the large trunks of the portal vein, and in the external iliac, renal and azygos veins. In the inferior vena cava, renal and portal veins they extend through the whole thickness of the outer coat, but in the other veins mentioned a layer of connective and elastic tissue is found external to the muscular fibres. The white connective-tissue fibres in the *tunica adventitia* of the inferior vena cava are disposed in bundles which form a network of right and left hand spirals, and this arrangement, together with the elastic fibres, facilitates the lengthening and shortening of the vessel which occurs with

FIG. 653.—The upper portions of the femoral and long saphenous veins laid open to show valves. About two-thirds of natural size.



ascend and descent of the diaphragm.‡ The large veins which open into the heart are covered for a short distance with a layer of cardiac muscle continued on to them

* *A. Physiol. norm. et path.* p. 601.

† Consult *The Anatomy and Physiology of Capillaries*, by August Krogh, 1924.

‡ Consult *A Monograph on Veins*, by K. J. Franklin, Baltimore, 1937.

from the heart and in the case of the coronary sinus the covering is complete. Muscular tissue is wanting—(1) in the veins of the maternal part of the placenta; (2) in the venous sinuses of the dura mater and the veins of the pia mater; (3) in the veins of the retina; (4) in the veins of the spongy substance of bones; (5) in the venous spaces of the corpora cavernosa and corpus spongiosum. The veins of the above-mentioned parts consist of an endothelial lining supported on connective tissue.

Most veins are provided with *valves* which serve to prevent the reflux of the blood (fig. 653). Each valve is formed by a reduplication of the inner coat, strengthened by connective tissue and elastic fibres, and is covered on both surfaces by endothelium, the arrangement of which differs on the two surfaces. On the surface of the valve next the wall of the vein, the cells are arranged transversely; while on the other surface, over which the current of blood flows, the cells are arranged longitudinally in the direction of the current. Most commonly two such valves are found opposite one another, more especially in the smaller veins or in the larger trunks at the point where they are joined by smaller branches; occasionally there are three, and sometimes only one. The valves are semilunar. They are attached by their convex edges to the wall of the vein; the concave margins are free, directed in the course of the venous current, and lie in close apposition with the wall of the vein as long as the current of blood takes its natural course; if, however, any regurgitation takes place, the valves become distended, their opposed edges are brought into contact, and the current is interrupted. The wall of the vein on the cardiac side of the attachment of each valve is expanded into a pouch or sinus, which gives to the vessel, when injected or distended with blood, a knotted appearance. The valves are very numerous in the veins of the extremities, especially in the veins of the lower extremities, these vessels having to conduct the blood against the force of gravity in addition to being subjected to intermittent pressure due to muscular contractions. They are absent in the very small veins, i.e. those less than 2 mm. in diameter, also in the *venæ cavæ*, hepatic, renal, uterine and ovarian veins. The cerebral and spinal veins, the veins of the spongy tissue of bone, the pulmonary veins, and the umbilical vein and its branches, are also destitute of valves. A few valves are found in each testicular vein, and one also at its termination. A few valves are occasionally found in the azygos and intercostal veins. Valves are present in the tributaries of the portal vein in the *fœtus* and for a short time after birth; as a rule they soon atrophy and disappear, but sometimes they persist in a degenerate form.

The return of blood along the veins is under the influence of a number of factors: the smaller veins are filled by the blood overflowing into them from the capillary bed. The deep veins of the limbs are subjected to pressure due to contractions of the surrounding muscles and the *venæ comitantes* are affected in a similar way by arterial pulsations. This squeezing of the veins would tend to drive the blood in both directions along the vessels but the valves prevent flow towards the periphery and so the blood must flow towards the heart so long as the valves are competent. The force of gravity in the veins of the head and neck and the suction due to negative intrathoracic pressure in the veins near the heart are also important factors in venous return.

The rate of flow of the blood in veins being slower than in the arteries, veins are larger and more numerous than the corresponding arteries so that the blood delivered to the tissues can be adequately returned to the heart.

The larger veins, like the arteries, are supplied with nutrient vessels, termed *vasa vasorum*. Unlike those in the arteries these vessels may penetrate as far as the intima. Nerves also are distributed to the veins in the same manner as to the arteries, but in much fewer numbers.

*Arterio-venous Anastomoses.**—In a number of situations in the body direct connexions exist between the smaller arteries and the corresponding veins. The connecting vessel may be straight or coiled and in the latter case it always possesses a thick muscular coat of peculiar structure and a relatively fine lumen, measuring $10\text{ }\mu\text{--}30\text{ }\mu$ on the average. Under the influence of the sympathetic nervous system, which gives a very rich supply of unmyelinated fibres to the wall of the vessel, it is capable of complete closure and in that event the circulation passes through the capillary bed in the ordinary way. When patent, the vessel carries blood directly from the artery to the vein and so partially or completely excludes the capillary bed from the circulation for the time being.

Arterio-venous anastomoses have been demonstrated in the skin of the palmar surfaces of the digits, the nail-beds, the thenar and hypothenar eminences and in similar situations in the foot. They have also been described in the skin of the ear and the nose, in the mucous membrane of the nose † and the alimentary canal and in the

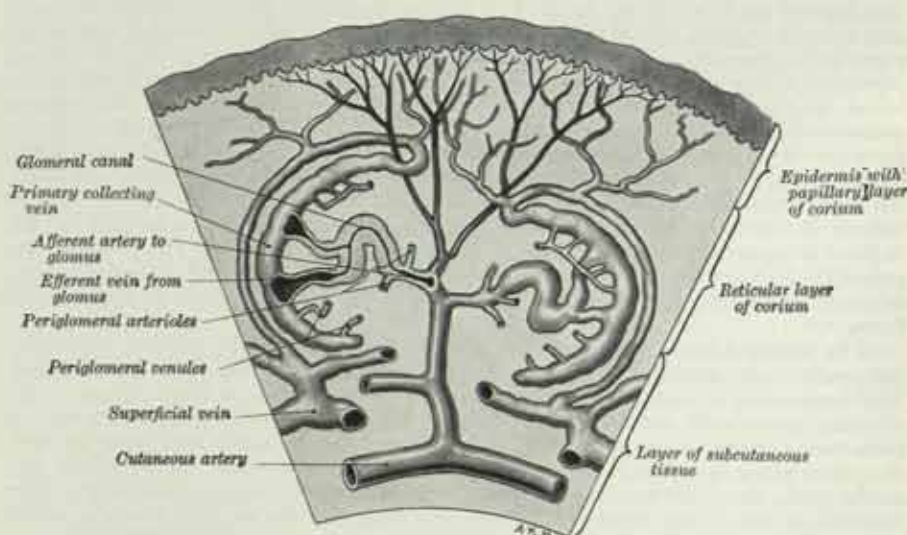
* For a review of the present position of our knowledge on this subject and for references to the literature, consult a paper by Eliot R. Clark, *Physiological Reviews*, 18, 1938.

† Harper and Boyd, *Proc. Anat. Soc., J. Anat.*, 81, 1947.

coccygeal body (p. 1534) as well as in the erectile tissue of the sexual organs (p. 1503). It is probable that they occur also in other situations in the body.

The digital anastomoses exhibit a special arrangement and form a large number of small units which have been termed 'glomera'. They are situated in the deeper layer of the corium and each 'glomus' has one or more afferent arteries. These vessels arise from branches of the cutaneous arteries which run towards the skin surface (fig. 654). The afferent arteries come off at right angles from their parent vessels, which thereafter are continued into the papillary layer of the corium, where they end in a capillary plexus. A short distance from its origin the afferent artery of a glomus gives off a number of fine 'periglomerular' branches and at once becomes considerably enlarged. It makes an S-shaped curve and then narrows down to become continuous with a short funnel-shaped vein which opens, at right angles, into a collecting vein. This vein commences on the deep aspect of the glomus, and curves round its outer surface. Having gained the superficial aspect of the glomus the collecting vein retraces its course, receiving venules from the papillary layer of the skin as it does so. Finally it joins one of the deeper cutaneous veins.

FIG. 654.—Scheme of two cutaneous arterio-venous anastomoses. (Modified from Popoff.*)



On the left half of the figure some of the vessels have been opened to show the relative thickness of their walls.

Structurally the vessels immediately concerned in the digital arterio-venous anastomoses are unusual. At the point where it enlarges into the connecting vessel the afferent artery presents a number of small endothelio-muscular elevations which project into its lumen, but proximal to this point its structure is normal. The connecting vessel has a lining of endothelium, supported by some fine collagenous fibres, but is devoid of an internal elastic lamina. An inner longitudinal and an outer circular muscle coat are not sharply differentiated from one another. The muscular wall is thick and on section the muscle fibres appear pale and swollen, with centrally situated nuclei, so that they have been described as 'epithelioid'. The emerging vein has a thin wall, the muscular coat being entirely wanting. Numerous elastic fibrils are present and are continued into the tunica adventitia of the collecting vein.*

Experimental evidence † has confirmed the view that the glomera play an important part in regulating body temperature both generally and locally. When the local temperature of the rabbit's ear is raised above 40° C. the connecting vessel relaxes and an increased flow of blood at body temperature results, with a consequent cooling effect. When the local temperature is lowered below 15° C. the connecting vessel again relaxes. In this case the increased flow of blood at body temperature will help to raise the local temperature unless the process of artificial cooling is intensified. Again, when the body temperature of a rabbit is raised artificially there is a general opening up of all the subcutaneous arterio-venous anastomoses, a considerable increase in heat radiation and a consequent drop in the body temperature.

* N. W. Popoff, *Arch. Path.*, 18, 1934.

† R. T. Grant, *Heart*, 15, 1930.

It is to be noted that these arterio-venous anastomoses are not fully developed in number or in structure in the child at birth, although they develop rapidly in the early months of life. Their paucity and their undeveloped character render the temperature-regulating mechanism imperfect in the new-born, and this is one of the serious disadvantages under which the child labours in the first few weeks of life. In old age the subcutaneous arterio-venous anastomoses show a marked reduction in number, and the frequency with which old people suffer from coldness of the hands and feet may be associated with their disappearance.

The arterio-venous anastomoses present in the mucous membrane of the alimentary canal * fulfil a very different function. In man the arteriole to a villus has a direct connexion with its corresponding venule and, during periods when absorption is not occurring, the connexion becomes patent and serves to raise the pressure in the portal vein. On the other hand, during active absorption the connexion is closed and the circulation passes through the capillary plexus at the apex of the villus. Arterio-venous communications have been described also in the stomach.†

THE THORACIC CAVITY

The shape and the skeletal walls of the thoracic cavity are described on pp. 253, 254. Its chief contents are the heart and the two lungs.

The inlet of the thorax (figs. 685, 701, 702).—(The bony boundaries of the inlet are described on p. 253). The structures which pass through the upper opening of the thorax fall naturally into two groups, viz.: those in or near the median plane and those placed more laterally on each side in close relationship with the cervical parts of the pleurae and lungs.

In or near the median plane.—Just behind the manubrium, the lowest parts of the Sternohyoid muscles just enter the thorax. Immediately behind this are the Sternothyroid muscles, the remains of the thymus and the inferior thyroid veins on their way to their termination in the brachiocephalic (innominate) vein. In the child, in particular, the left brachiocephalic vein itself may be so highly placed as to cross over to the right side actually in the thoracic inlet. More posteriorly, the trachea and the œsophagus, together with the recurrent laryngeal nerves, occupy the median region and, behind the left margin of the œsophagus, the thoracic duct enters the neck. Just in front of the vertebral column are the Longus colli (cervicis) muscles and the anterior longitudinal ligament.

On each side the upper part of the pleura and the apex of the lung occupy the thoracic inlet. Between the pleura and the neck of the first rib from the medial to the lateral side lie the sympathetic trunk, the superior intercostal artery and the ventral ramus of the first thoracic nerve passing obliquely upwards and laterally to join the lower trunk of the brachial plexus. Anteriorly, between the pleura and the first costal cartilage the internal thoracic (mammary) artery enters the thorax.

On the right side (fig. 701), the brachiocephalic artery leaves the chest between the trachea and the pleura. The vagus nerve, having passed at a higher level between the subclavian artery and vein, lies at the thoracic inlet between the pleura and the brachiocephalic artery. The right brachiocephalic vein enters the thorax anterolateral to the brachiocephalic artery and the right phrenic nerve crosses the internal thoracic artery and comes to lie lateral to the brachiocephalic vein as these vessels pass behind the first costal cartilage.

On the left side (fig. 702), the left common carotid and subclavian arteries leave the thorax between the pleura laterally and the trachea medially; the left vagus nerve is running downwards lateral to the interval between the two vessels. Anterolateral to this is the left brachiocephalic vein. The left phrenic nerve crosses the internal thoracic artery at a higher level than it does on the right side so that, at the thoracic inlet it is running in the interval between the left brachiocephalic vein anterolaterally and the subclavian and carotid vessels posteromedially.

The **outlet of the thorax** is wider transversely than from before backwards. It slopes obliquely downwards and backwards, so that the thoracic cavity is much longer behind than in front. The Diaphragm (p. 585) closes the opening and forms a convex floor for the thorax. The floor is flatter at the centre than at the periphery, and higher on the right side than on the left; in the dead body the right side of the

* R. Spanner, *Anat. Anz.*, 71, 1931.

† T. E. Barlow, *J. Anat.*, 85, 1951.

floor reaches the level of the upper border of the fifth costal cartilage, while the left extends only to the corresponding part of the sixth costal cartilage. From the highest point on each side the floor slopes suddenly downwards to the costal and vertebral attachments of the Diaphragm; this slope is more marked and longer behind than in front, so that only a narrow space is left between the Diaphragm and the posterior wall of the thorax.

The thoracic cavity.—The capacity of the thoracic cavity does not correspond with the bony thorax, because the lower part of the space enclosed by the ribs is occupied by some of the abdominal viscera. On the other hand, the thoracic cavity extends for a short distance into the neck above the anterior parts of the first ribs. During life the size of the thoracic cavity is constantly varying with the movements of the ribs and Diaphragm.

The thoracic cavity is divided into right and left parts by a septum, termed the *mediastinum*, which stretches from the back of the sternum to the vertebral column, and extends from the thoracic inlet above to the Diaphragm below. The heart lies in the mediastinum, enclosed within a fibroserous sac, termed the *pericardium*; the lungs occupy the right and left parts of the thoracic cavity. Each lung is covered with a serous membrane, called the *pleura*, which also lines the wall of the corresponding half of the chest, and forms the lateral boundary of the mediastinum (fig. 664).

For purposes of description the mediastinum is divided into a superior and an inferior part. The *superior part* extends downwards from the thoracic inlet as far as an oblique plane passing through the lower edge of the manubrium sterni in front and the lower border of the fourth thoracic vertebra behind. The *inferior part*, below this plane, is subdivided into three portions, viz. an *anterior* in front of the pericardium, a *posterior* behind the pericardium and Diaphragm, and a *middle*, which contains the pericardium, the heart and the large vessels entering or leaving the latter (fig. 664). Details of the contents of the different parts of the mediastinum are given with the description of the respiratory organs.

THE PERICARDIUM

The **pericardium** (figs. 655 and 664) is a conical, fibroserous sac, which contains the heart and the roots of the great vessels. It is placed in the mediastinum behind the body of the sternum and the cartilages of the ribs from the second to the sixth inclusive, and in front of the thoracic vertebrae, from the fifth to the eighth inclusive.

The pericardium comprises two sacs intimately connected with one another, but different in structure. The outer sac, known as the *fibrous pericardium*, consists of fibrous tissue. The inner sac, or *serous pericardium*, is a delicate membrane which lines the fibrous sac and covers the heart. The heart invaginates the wall of the serous sac from above and behind, and practically obliterates its cavity, the space being a potential one.

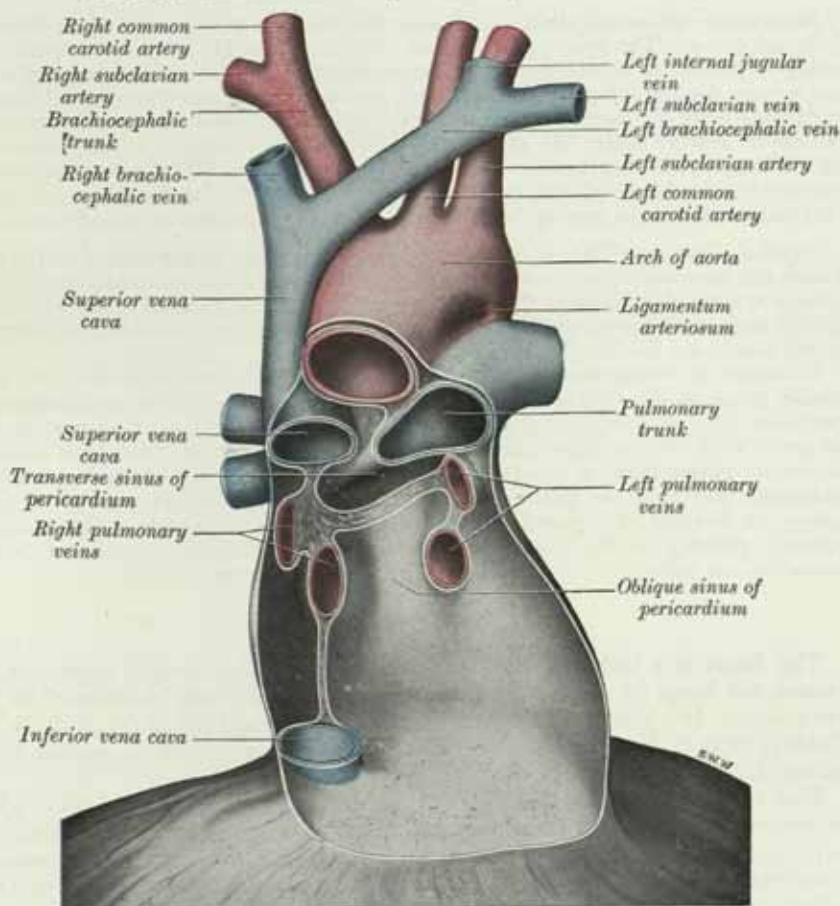
The *fibrous pericardium* is a cone-shaped bag, the apex of which is truncated and continuous with the external coats of the great vessels, while its base is attached to the central tendon and to a small part of the muscular substance of the left half of the Diaphragm. In some of the lower mammals the base is either completely separated from the Diaphragm or joined to it by some loose fibrous tissue; in man much of its diaphragmatic attachment consists of loose fibro-areolar tissue which can be readily broken down, but over a small area the central tendon of the Diaphragm and the pericardium are fused. Above, the fibrous pericardium not only blends with the external coats of the great vessels, but is continuous with the pretracheal fascia (p. 566). The fibrous pericardium is also attached to the posterior surface of the sternum by a *superior* and an *inferior sternopericardial ligament*, the superior passing to the upper end of the body, and the inferior to the lower end. By means of all these connexions it is securely anchored within the thoracic cavity and therefore maintains the heart in position within the chest. It also prevents over-distension of the heart.

Anteriorly, the fibrous pericardium is separated from the front wall of the thorax, in the greater part of its extent, by the lungs and pleurae; but a small area, usually corresponding with the left half of the lower part of the body of the sternum and the sternal ends of the cartilages of the fourth and fifth ribs of the left side, is in direct

relationship with the chest-wall. Until puberty or adolescence the lower end of the thymus is in contact with the front of the upper part of the pericardium. *Posteriorly*, the fibrous pericardium rests upon the bronchi, the œsophagus, the œsophageal plexus of nerves, the descending thoracic aorta and the posterior part of the mediastinal surface of each lung. *Laterally*, it is covered by the pleuræ, and is in relation with the mediastinal surfaces of the lungs; the phrenic nerve, with its accompanying vessels, descends between the pericardium and the mediastinal pleura on each side. *Inferiorly*, it is separated from the liver and the fundus of the stomach by the Diaphragm.

The vessels receiving prolongations from the fibrous pericardium are: the aorta, the superior vena cava, the right and left pulmonary arteries, and the four

FIG. 655.—The interior of the pericardium, viewed from in front.



pulmonary veins. The inferior vena cava, which enters the pericardium through the central tendon of the Diaphragm, receives no covering from the fibrous layer.

The *serous pericardium* is, as already stated, a closed sac which lines the fibrous pericardium and is invaginated by the heart; it therefore consists of a *visceral* and a *parietal* portion and allows free movement of the heart within the fibrous pericardium. The visceral portion, or *epicardium*, covers the heart and the great vessels, and from the latter it is reflected to form the parietal layer, which lines the fibrous pericardium. The portion which covers the vessels is arranged in the form of two tubes. The aorta and pulmonary trunk are enclosed in one tube; the superior and inferior venæ cavæ and the four pulmonary veins are enclosed in a second tube, the attachment of which to the parietal layer is Ω -shaped (fig. 655). The cul-de-sac between the limbs of the Ω lies behind the left atrium and is known as the *oblique sinus*, while the passage between the aorta and pulmonary trunk, in front, and the atria, behind, is named the *transverse sinus* (figs. 662 and 677). The upper boundary of the transverse sinus is shown in fig. 655.

Between the left pulmonary artery and subjacent pulmonary vein is a triangular fold of the serous pericardium, known as the *ligament of the left vena cava*. It is formed by the folding of the serous layer over the remnant of the left duct of Cuvier (left superior vena cava) (p. 175). The fold often forms the anterior wall of a small, blind recess, the mouth of which is directed to the left. The lumen of the left duct of Cuvier is obliterated during foetal life, but its wall persists as a fibrous band stretching from the upper part of the left superior intercostal vein to the back of the left atrium, where it is continuous with a small vein, termed the *oblique vein of the left atrium*, which opens into the coronary sinus (fig. 658).

Vessels and nerves.—The *arteries* of the pericardium are derived from the internal thoracic arteries and their musculophrenic branches, and from the descending thoracic aorta; its *nerves* are derived from the vagus and phrenic nerves, and the sympathetic trunks.

Structure.—As stated above, the fibrous pericardium consists of a dense feltwork of fibrous tissue. The serous pericardium consists of a single layer of flattened cells resting on a layer of subserous areolar tissue which, in the case of the parietal layer, blends with the fibrous pericardium. The areolar tissue under the visceral layer is continuous with the interstitial tissue of the myocardium and contains fat which is greatest in amount along the ventricular border of the coronary sulcus, along the inferior border of the heart and in the interventricular grooves. The main trunks of the coronary vessels and their larger branches are embedded in this fat, the amount of which is related to that of the general body fat and gradually increases as age advances.

Applied Anatomy.—Paracentesis of the pericardium may be performed in the fifth or sixth left intercostal space near the sternum, with care to avoid wounding the internal thoracic artery. Alternatively the exploring needle may be entered at the left costo-xiphoid angle, and passed upwards and backwards into the pericardial sac, or lateral to the left mammary line in the fifth or sixth interspace.

It should be remembered that the serous pericardium, which clothes the pulmonary trunk on the wall of the transverse sinus, extends as far as the ligamentum arteriosum (p. 726). When the ductus arteriosus persists as a patent connexion with the aortic arch, the condition may call for surgical intervention, when it is divided, the serous pericardium is involved, and must either be reflected back on to the pulmonary trunk or the pericardium must be opened. In uncomplicated cases ligature or division of a patent ductus usually cures the condition. Occasionally, however, patency of the ductus may be associated with other congenital cardiac anomalies, e.g. pulmonary stenosis or coarctation of the aorta (p. 794).

THE HEART

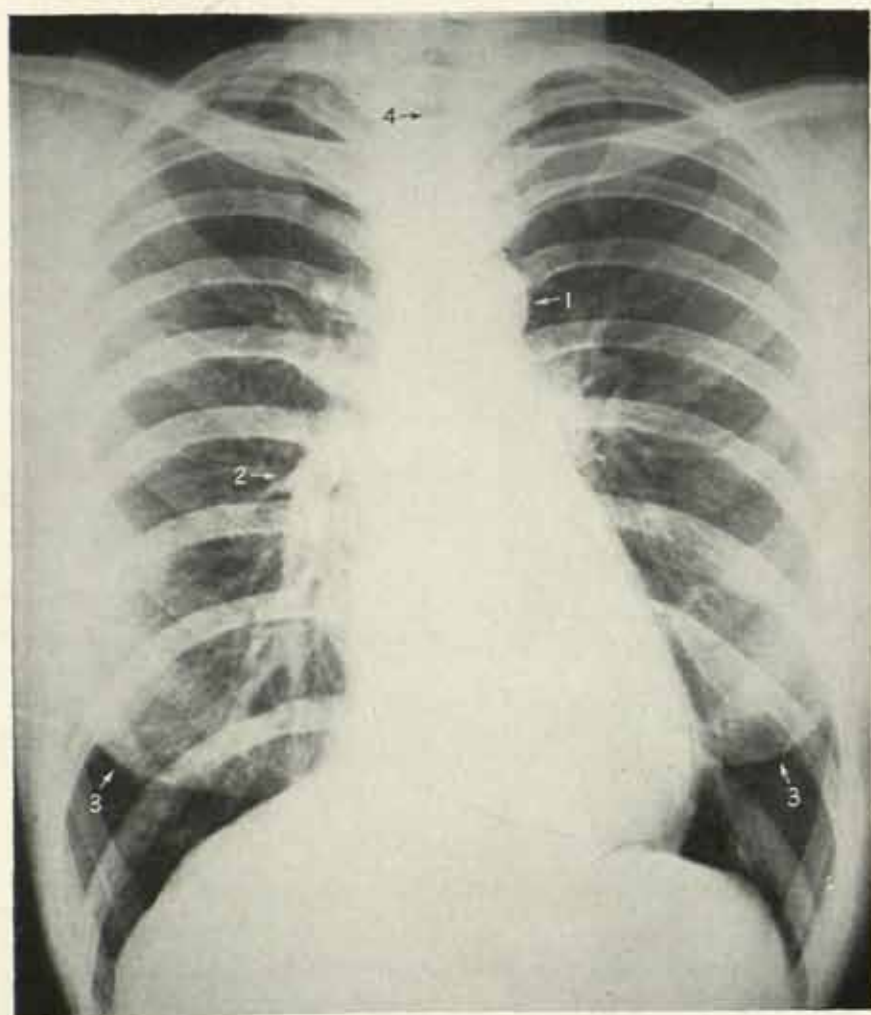
The **heart** is a hollow, muscular organ of a somewhat conical form; it lies between the lungs in the middle mediastinum (fig. 656), and is enclosed in the pericardium. It is placed obliquely in the chest behind the body of the sternum and adjoining parts of the rib cartilages, one-third of it on the right of the median plane and two-thirds on the left (Pl. XIX).

Size.—The heart of the adult measures about 12 cm. from base to apex, 8 to 9 cm. transversely at the broadest part, and 6 cm. anteroposteriorly. Its weight, in the male, varies from 280 to 340 grammes; in the female, from 230 to 280 grammes. It continues to increase in weight and size up to an advanced period of life, and this increase is more marked in men than in women.

External features.—As already stated (p. 694) the heart is divided into four chambers, viz. right and left atria, and right and left ventricles: the division is indicated on the surface of the heart by grooves or sulci. The atria are separated from the ventricles by the *coronary sulcus*; this groove contains the trunks of the coronary vessels of the heart, and is deficient in front, where it is crossed by the root of the pulmonary trunk. The *interatrial groove*, separating the two atria, is scarcely marked on the posterior surface, while anteriorly it is hidden by the pulmonary trunk and aorta. The ventricles are separated by two grooves, termed the *anterior* and *posterior interventricular grooves*; the former is situated on the sternocostal surface of the heart, near its left margin, the latter on the diaphragmatic surface near the right margin; these grooves extend from the base of the ventricular portion to a notch, termed the *incisura apicis cordis*, situated a little to the right of the apex of the heart.

The *base* (fig. 658) is somewhat quadrilateral in form; it faces backwards and to the right, and is separated from the thoracic vertebræ (fifth to eighth in the

PLATE XIX



Radiograph of chest, antero-posterior view. Adult female. Note the difference in the level of the right and left halves of the diaphragm.

1. Aortic 'knuckle.' 2. Pulmonary vessels of right side. 3. Edge of shadow caused by breast. 4. Trachea.

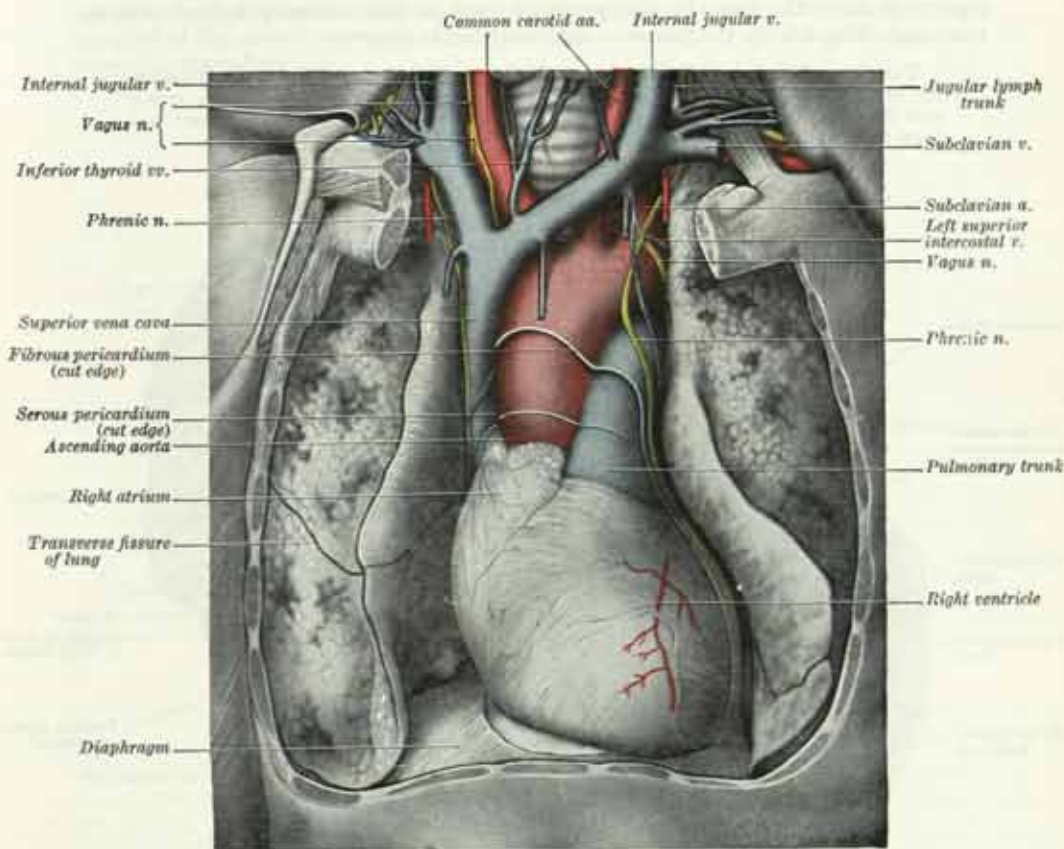
PLATE XX



Radiograph showing the œsophagus during the passage of a barium meal. Note that in the upper part of the œsophagus longitudinal folds in the mucous membrane can be identified. The upper arrow points to the shadow of the right principal bronchus ; the lower arrow indicates the tenth thoracic vertebra. Note that the lower part of the œsophagus inclines forwards away from the vertebral column.

recumbent, sixth to ninth in the erect posture) by the pericardium, right pulmonary veins, œsophagus and aorta. It is formed mainly by the left atrium, and, to a small extent, by the posterior part of the right atrium. Above, it extends as high as the bifurcation of the pulmonary trunk; below it is bounded by the posterior part of the coronary sulcus, containing the coronary sinus. On the right it is limited by the rounded right border of the right atrium, and on the left by the rounded left border of the left atrium. The four pulmonary veins, two on each side, open into the left atrium, whilst the superior vena cava opens into the upper part, and the inferior vena cava into the lower part, of the right atrium. The

FIG. 656.—A dissection to display the heart, great vessels and lungs *in situ*.



The sternum and the sternal ends of the costal cartilages, together with the parietal pleura on each side, have been excised, and the mediastinal pleura and parietal layer of the pericardium over the antero-superior surface of the heart have been removed. Both lungs have been retracted to expose the heart fully, and the epicardium has been dissected off the heart and the roots of the great vessels.

On the right side, the inferior cardiac branch of the vagus nerve descends between the brachiocephalic (innominate) artery and the right brachiocephalic vein. On the left side, a communication descends from the left superior intercostal vein and crosses the aortic arch and the left pulmonary artery to become continuous with the oblique vein of the left atrium.

portion of the left atrium between the openings of the right and left pulmonary veins constitutes the anterior wall of the oblique sinus of the pericardium (p. 703).

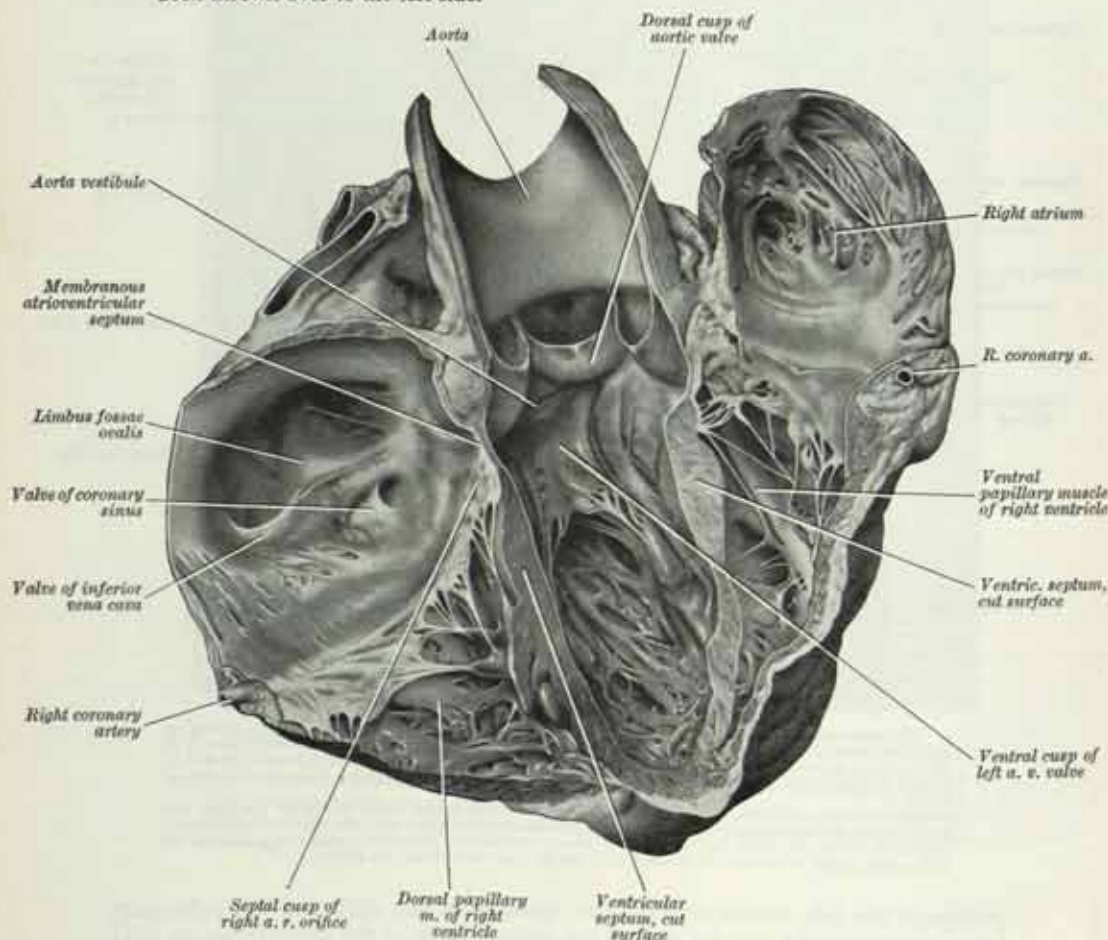
The *apex*, formed by the left ventricle, is directed downwards, forwards and to the left, and is overlapped by the left lung and pleura.

The *sternocostal surface* (fig. 659) is directed forwards, upwards and to the left. It consists of an atrial and a ventricular portion, the former being above and to the right, the latter below and to the left, of the anterior part of the coronary sulcus. The atrial portion is almost entirely formed by the right atrium; the greater part of the left atrium is hidden by the ascending aorta and pulmonary trunk (fig. 659), and only a small part of its auricle projects forwards on the left side of the pulmonary trunk. Of the ventricular portion about one-third is formed by the left, and two-thirds by the right ventricle, the line of separation between the ventricles

being marked by the anterior interventricular groove. The sternocostal surface is separated by the pericardium from the body of the sternum, the Sternocostalis muscles and the cartilages of the third, fourth, fifth and sixth ribs; owing to the bulging of the heart towards the left side, the part of the surface which lies behind the left rib-cartilages is much larger than the part which lies behind the right. The sternocostal surface is also covered by the pleuræ and the thin, anterior parts of the lungs, with the exception of a small, triangular area corresponding with the cardiac notch in the left lung.

The *diaphragmatic surface* (fig. 658), directed downwards and slightly backwards, is formed by the ventricles (chiefly by the left ventricle), and rests upon the central tendon and a small part of the left muscular portion of the Diaphragm. It is separated from the base by the posterior part of the coronary sulcus, and is traversed obliquely by the posterior interventricular groove.

FIG. 657.—The interior of the heart. This view has been obtained by incising the organ along its right and lower margins and by excising the pulmonary trunk and the infundibulum. Thereafter the rest of the ventral portion of the heart has been thrown over to the left side.



The *left surface* is directed upwards, backwards and to the left. It is formed almost entirely by the left ventricle, but a small part of the left atrium and its left auricle contribute to its formation superiorly. Convex from before backwards and from above downwards, it is widest above, where it is crossed by the coronary sulcus, and narrowest at the apex. It is separated by the pericardium from the left phrenic nerve and its accompanying vessels, and by the left pleura from the deep hollow on the left lung, below and in front of the hilus.

The *right margin*, formed by the right atrium, is rounded and almost vertical.

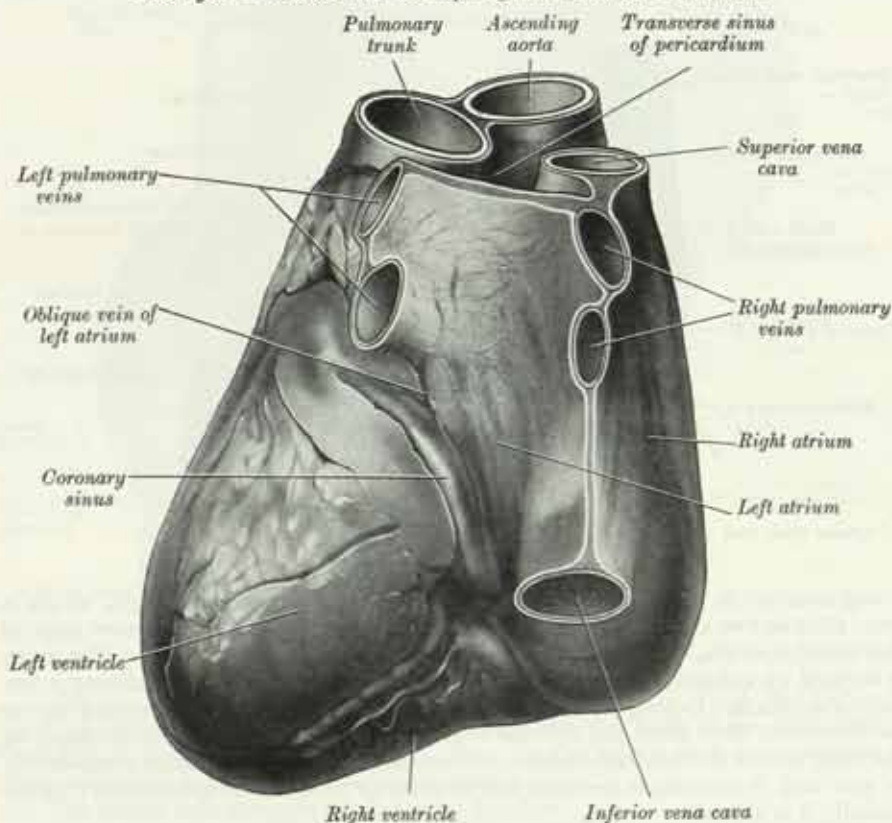
The *inferior margin*, formed almost entirely by the right ventricle, is nearly horizontal, and extends from the lower limit of the right border to the apex.

The *left margin* is rounded, and is formed mainly by the left ventricle, but to a slight extent, above, by the left auricle. It extends from the left auricle, obliquely downwards, with a convexity to the left, to the apex of the heart, and separates the sternocostal from the left surface.

The interatrial septum.—A partition, named the *interatrial septum* (figs. 660, 664, 676), intervenes between the right and left atria, and is placed so obliquely that the right atrium lies in front and to the right of the left atrium.

The **right atrium** (figs. 659, 660) is a somewhat quadrangular chamber which forms the right surface of the heart. The superior vena cava opens into its upper and posterior part and the inferior vena cava into its lower and posterior part. A small, conical, muscular pouch, termed the *auricle*, projects towards the left from its upper and anterior part and overlaps the right side of the root of the aorta. The margins of the auricle are notched, and its interior is encroached on by an irregular, muscular reticulum.

FIG. 658.—The base and the diaphragmatic surface of the heart.



Note.—The cut edges of the serous pericardium are clearly shown.

In well fixed hearts the outer surface of the lateral wall of the atrium is marked by a shallow groove, termed the *sulcus terminalis*, which extends between the right sides of the orifices of the superior and inferior venæ cavæ.

Anteriorly, the right atrium is related to the anterior part of the mediastinal surface of the right lung and is separated from it by the pleura and the pericardium. *Laterally*, it is related to the mediastinal surface of the right lung in front of the hilus but is separated from it by the pleura, the right phrenic nerve and pericardiophrenic vessels and the pericardium. *Posteriorly* and to the left (fig. 664), the right atrium is related to the left atrium and is separated from it by the interatrial septum; posteriorly and to the right, it is related to the right pulmonary veins. *Medially*, it is related to the commencement of the ascending aorta and, to a less extent, to the root of the pulmonary trunk.

The *interior of the right atrium* (fig. 660) presents two main parts for examination: The posterior portion, into which open the great veins, is derived embryo-

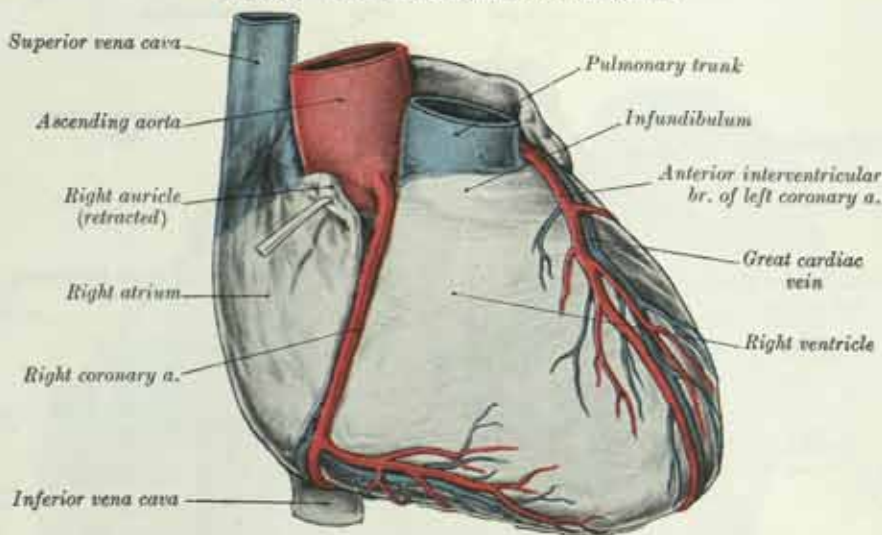
logically from the absorbed right horn of the sinus venosus ; it has smooth walls and is termed the *sinus venarum*. Anterior to this is a portion with ridged walls derived embryologically from the *atrium* proper and which is in continuity anteriorly with the *auricle*. The atrium communicates with the right ventricle through the atrioventricular opening.

The *sinus venarum*. This portion includes the posterior portion and the lateral wall of the cavity as far forwards as the *crista terminalis* (p. 709). Opening into it are the following vessels :

The *superior vena cava* (figs. 659, 660) returns the blood from the upper half of the body, and opens into the upper and posterior part of the atrium. Its orifice is directed downwards and forwards, and has no valve.

The *inferior vena cava* (fig. 660), larger than the superior, returns the blood from the lower half of the body, and opens into the lowest part of the atrium near the interatrial septum. The orifice is guarded anteriorly by a rudimentary valve, termed the *valve of the inferior vena cava*. The valve is semilunar in form, its convex margin

FIG. 659.—The sternocostal surface of the heart.



being attached to the anterior margin of the orifice ; its concave margin, which is free, ends in two cornua, of which the left is continuous with the anterior edge of the annulus ovalis, while the right is lost on the wall of the atrium. The valve is formed by a duplication of the lining membrane of the atrium, enclosing a few muscular fibres. During intrauterine life this valve is of large size, and serves to direct the flow from the *inferior vena cava* into the *left atrium* through an opening, named the *foramen ovale*, in the interatrial septum. It varies considerably in size and it sometimes presents a cribriform or filamentous appearance ; occasionally it is absent.

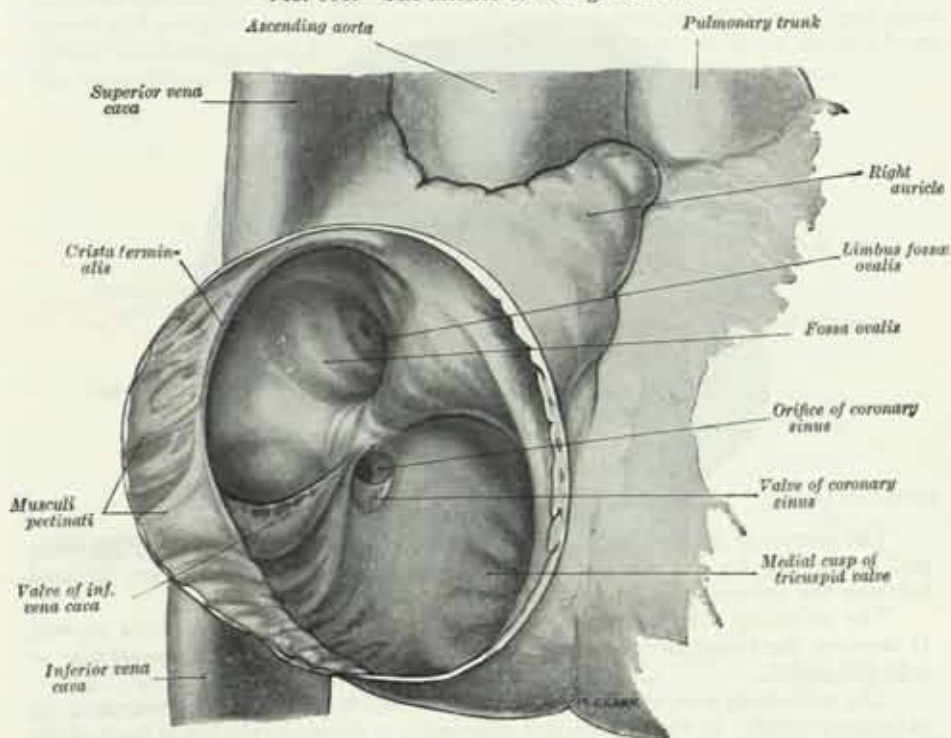
The *coronary sinus* (fig. 658) returns the greater part of the blood from the substance of the heart. Its opening is placed between the orifice of the inferior vena cava and the atrioventricular opening, and is protected by a thin, semi-circular valve, termed the *valve of the coronary sinus* (fig. 660), a semicircular fold of the lining membrane of the atrium, which covers the lower part of the orifice. It prevents the regurgitation of blood into the sinus during the contraction of the atrium. This valve may be double or it may be cribriform.

The *foramina venarum minimarum* are the orifices of minute veins (*venæ cordis minimæ*), which return a small quantity of blood directly from the substance of the heart. They are more numerous on the septal wall than elsewhere. Other smaller orifices opening into the atrium are those of the anterior cardiac veins and sometimes of the right marginal vein (p. 837).

The *intervenous tubercle* is a small projection on the posterior wall of the atrium, just below the orifice of the superior vena cava. It is distinct in the hearts of quadrupeds, but in man is scarcely visible. During intrauterine life it may direct the blood from the superior vena cava towards the right atrioventricular opening.

The atrium proper and the auricle.—This portion is separated from the sinus venarum by the *crista terminalis*, a smooth, muscular ridge, which is placed mainly on the lateral wall of the right atrium. It begins on the upper part of the septum and, after passing anterior to the orifice of the superior vena cava, skirts the right margin of that orifice and then extends to the right side of the orifice of the inferior vena cava, where it is connected to the right end of the valve of the latter vessel. It occupies the site of the right venous valve of the embryo (p. 158) and corresponds in position with the *sulcus terminalis* (p. 707) on the outside of the heart. It indicates the junction between the part of the heart derived from absorption of the right horn of the sinus venosus and the part derived from the original atrium.

FIG. 660.—The interior of the right atrium.



The *musculi pectinati* are nearly parallel muscular ridges which run forwards from the *crista terminalis* across the lateral and anterior walls of the right atrium, inclining towards the atrioventricular orifice. In the auricle they are connected to one another so as to form a muscular network.

The septal wall presents the following features :

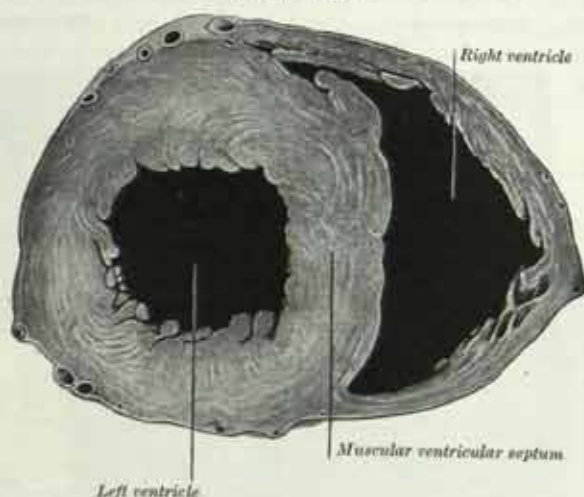
The *fossa ovalis* (fig. 660) is an oval depression on the lower part of the septal wall of the atrium, above and to the left of the orifice of the inferior vena cava. Its floor is formed originally by the septum primum of the foetal heart (p. 160).

The *limbus fossae ovalis* (fig. 661) is the prominent margin of the fossa ovalis and represents the free edge of the septum secundum (p. 161) of the embryonic heart. It is most distinct above and at the sides of the fossa; below, it is deficient. Its anterior edge is continuous with the left horn of the valve of the inferior vena cava. A small, slit-like, valvular opening is occasionally found, at the upper margin of the fossa, leading upwards, beneath the limbus, into the left atrium; it is the remains of the foramen ovale between the two atria.

The **right ventricle** (figs. 659, 661, 663) extends from the right atrium nearly to the apex of the heart. Its *anterosuperior surface* is convex, and forms a large part of the sternocostal surface of the heart. In the greater part of its extent it is separated from the chest wall only by the pericardium, but the left pleura and, to a lesser extent, the anterior margin of the left lung are interposed both above and to the left side (fig. 667). Its *inferior surface* is flattened and is related to the central tendon and

the adjoining part of the Diaphragm, but is separated from it by the pericardium. Its *left*, or *posterior*, wall is formed by the ventricular septum, which bulges into the right ventricle, so that a transverse section of the cavity presents a crescentic outline (fig. 661). Its upper left angle forms a conical pouch, usually termed the *infundibulum*, from which the pulmonary trunk arises. A tendinous band (fig. 665), which is named the *tendon of the infundibulum*, connects the posterior surface of the infundibulum to the aorta; this tendon is continuous with the membranous part of the ventricular septum (p. 715). The wall of the right ventricle is thinner than that of the left, the proportion between them being as 1 to 3; it is thickest at the base and gradually becomes thinner towards the apex of the ventricle.

FIG. 661.—A transverse section through the ventricles of the heart.



The *interior of the right ventricle* (fig. 663) is separated into two parts, inflowing and outflowing, by a muscular ridge, termed the *supra-ventricular crest*, situated between the atrioventricular and pulmonary orifices.

The inflowing part has rough walls due to the presence of *trabeculae carneae*. It receives the blood from the right atrium through the *right atrioventricular or tricuspid orifice*.

The outflowing part, or *infundibulum*, has smooth walls and leads upwards to the *pulmonary orifice*. In the cadaver it is impossible to recognise the lower limit of the infundibulum on the surface of the heart but its lower and posterior limit is formed by the free rounded border of the supra-ventricular crest (fig. 663). The infundibulum represents a persistent part of the bulbus cordis which has been incorporated in the right ventricle, and its persistence as the outflow channel of this ventricle is attributable to the support it provides for the pulmonary valve during ventricular diastole. It has been shown experimentally in dogs that, when subjected to increased backward pressure, the pulmonary valve gives way much more readily than the aortic valve and it has been inferred that, in life, the muscular walls of the infundibulum retain their normal tonus throughout ventricular diastole* and so provide the necessary support for the valves.

The *right atrioventricular or tricuspid orifice* is the large, oval aperture between the right atrium and the right ventricle. Situated at the base of the ventricle, it is encircled by a fibrous ring, covered with the lining membrane of the heart; it is considerably larger than the left atrioventricular orifice, being sufficient to admit the tips of three or four fingers. It is guarded by the right atrioventricular valve.

The *orifice of the pulmonary trunk* is situated at the summit of the infundibulum, close to the ventricular septum; it is circular in form, and has a diameter of about 3 cm. It is placed above and to the left of the atrioventricular opening, and is guarded by the valve of the pulmonary trunk.

The *right atrioventricular (tricuspid) valve* (figs. 657, 663) guards the right atrio-

* Sir Russell Brock, *Guy's Hosp. Rep.*, 104, 1955.

ventricular orifice, and consists of three somewhat triangular cusps, named, *ventral*, *dorsal* and *septal* (*anterior*, *inferior* and *medial*); in the angles between the cusps small intermediate segments are sometimes seen. The ventral cusp, which is the largest, is interposed between the atrioventricular orifice and the infundibulum, while the septal cusp is in relation with the ventricular septum. Each cusp is formed by a duplicature of the lining membrane of the heart, strengthened by intervening layers of fibrous tissue. The central parts of the cusps are comparatively thick and strong, while their marginal portions are thin and translucent. Their bases are attached to the fibrous ring surrounding the atrioventricular orifice and are also joined to each other so as to form a continuous annular membrane, while their apices project into the ventricular cavity. Their atrial surfaces, directed towards the blood-current from the atrium, are smooth; their ventricular surfaces, directed towards the wall of the ventricle, are rough and irregular, and together with the apices and margins of the cusps, give attachment to a number of delicate, tendinous cords, which are termed the *chordæ tendinæ*. Blood-vessels and fibres derived from the musculature of the atrium are present in the basal third of each cusp.

FIG. 662.—The heart, viewed from above.



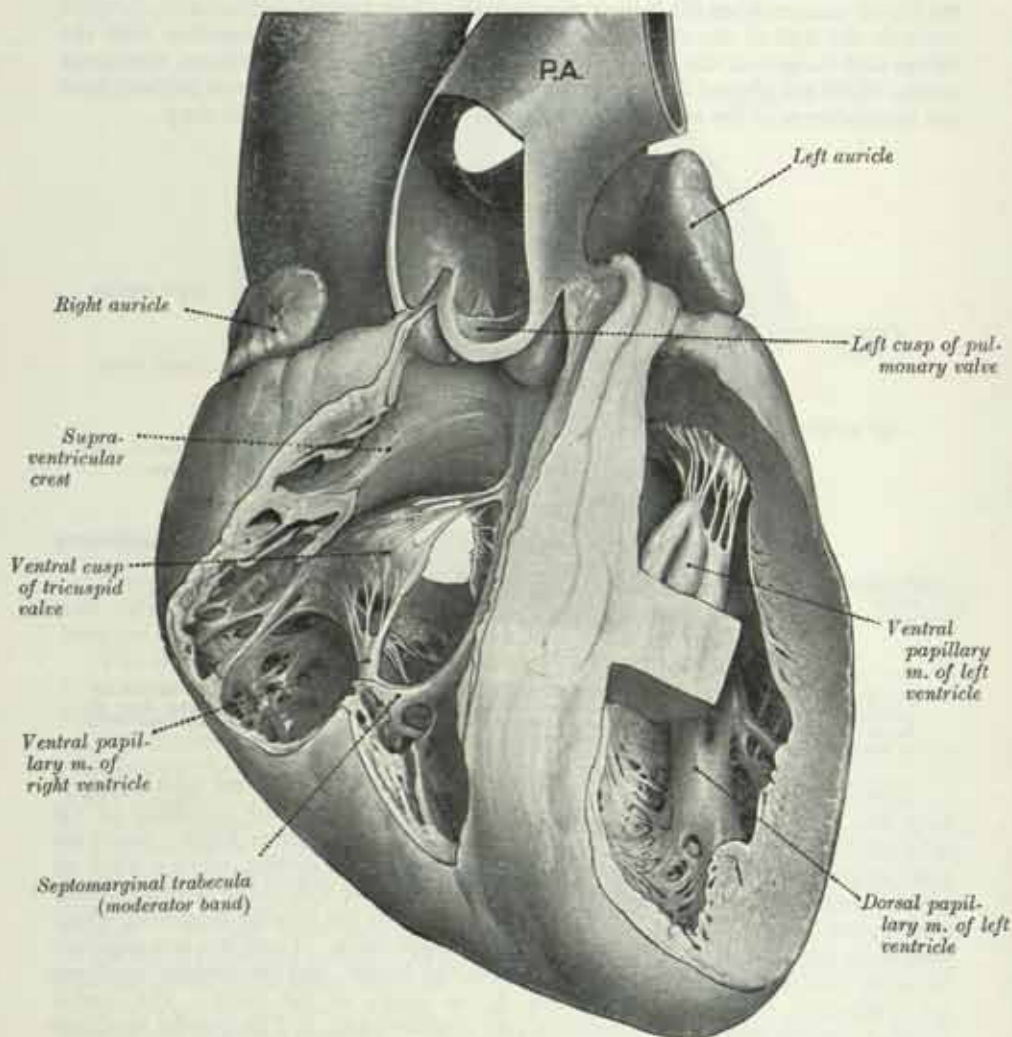
The white line which encloses the pulmonary trunk and aorta and those which enclose the pulmonary veins and the superior vena cava indicate the lines along which the parietal layer of the serous pericardium becomes continuous with the epicardium. The floor of the transverse sinus of the pericardium is seen from above, with the left coronary artery running in it.

The *trabeculæ carneæ* are round or irregular muscular columns which project from the whole of the inner surface of the ventricle, with the exception of the infundibulum, the wall of which is smooth. They are of three kinds: some are mere ridges, others are fixed at their ends but free in the middle, while a third set (*musculi papillares*) are continuous by their bases with the wall of the ventricle, while their apices project into the cavity, and give origin to the *chordæ tendinæ*, which pass to be attached to the segments of the tricuspid valve. There are two papillary muscles, ventral and dorsal; the ventral is the larger, and its *chordæ tendinæ* are connected with the ventral and dorsal cusps of the valve; the dorsal papillary muscle sometimes consists of two or three parts, and its *chordæ tendinæ* are connected with the dorsal and septal cusps. Some *chordæ tendinæ* also spring directly from the ventricular septum, or from small septal papillary muscles, and pass to the ventral and septal cusps. As a result of the inequality in size of the cusps, a considerable degree of overlapping occurs when the valve is held in the closed position by the contraction of the papillary muscles. A muscular band, well-marked in sheep and some other animals, frequently extends from the ventricular septum to the base of the ventral papillary muscle and serves to convey the right fasciculus of the atrioventricular bundle (p. 720). It may assist in preventing over-distension of the ventricle, and has been named the *septomarginal trabecula* (*moderator band*) (fig. 663).

The *pulmonary valve* (figs. 662, 663) consists of three semilunar segments or *valvules*, which are attached, by their convex margins, to the wall of the pulmonary trunk at its junction with the ventricle, their free borders being directed upwards

into the lumen of the vessel. Two of the cusps are situated anteriorly (right and left) and the third is posterior. Each consists of a duplication of the endocardium, with a little fibrous tissue interposed between the two endothelial layers. The free and attached margins are strengthened by tendinous fibres, and at the middle of the free margin there is a thickened *nodule*. From this nodule tendinous fibres radiate through the cusp to its attached margin, but are absent from two narrow crescentic portions, which are termed the *lunulae*. These are placed one on

FIG. 663.—A dissection of the ventricles, viewed from in front. (A. K. Maxwell.)
From Quain's *Elements of Anatomy*, 11th edition, vol. iv, part iii. *The Heart*,
by Professor Thomas Walmsley, 1929.



each side of the nodule, and immediately adjoining the free margin. Opposite to the semilunar cusps the pulmonary trunk presents three slight dilatations or sinuses.

The **left atrium** is rather smaller than the right, but its walls are thicker, measuring about 3 mm. A small somewhat conical pouch, termed the *auricle*, projects forwards from its upper left corner.

The cavity of the left atrium is formed to a large extent by the proximal parts of the pulmonary veins, which are incorporated during its development (p. 161). It is cuboidal in form, and extends to the right behind the right atrium, from which it is separated by the interatrial septum. Anteriorly, and to the left, it is concealed by the roots of the pulmonary trunk and aorta. Its posterior aspect forms most of the

base of the heart (p. 704) and lies in the anterior wall of the oblique sinus of the pericardium. Two pulmonary veins open into it on each side.

The *auricle* is somewhat constricted at its junction with the principal cavity; it is longer, narrower and more curved than that of the right atrium, and its margins are more deeply indented. It is directed forwards on the left side of the pulmonary trunk, and overlaps the root of this vessel.

The *interior of the left atrium* (fig. 666) presents several features for examination:

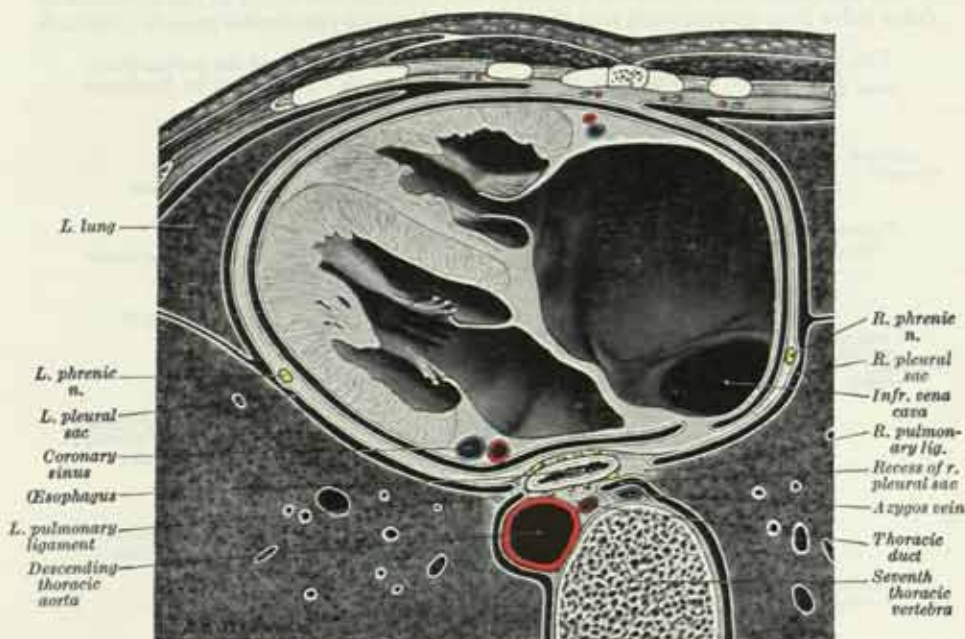
The *pulmonary veins*, four in number, open into the upper part of the posterior surface of the left atrium—two on each side of its middle line; their orifices are not provided with valves. The two left veins frequently end by a common opening.

The *left atrioventricular orifice* is the aperture between the left atrium and ventricle; it is described below.

The *foramina venarum minimarum* are the orifices of minute veins (*venæ cordis minimæ*) which return blood from the muscular substance of the heart.

The *musculi pectinati*, fewer and smaller than those in the right atrium, are confined to the inner surface of the auricle.

FIG. 664.—A transverse section through the mediastinum at the level of the body of the seventh thoracic vertebra.



On the atrial septum a lunate impression may be seen, bounded below by a crescentic ridge, the concavity of which is directed upwards. The depression coincides with the fossa ovalis of the right atrium.

The **left ventricle** is longer and more conical in shape than the right, and forms the apex of the heart. On transverse section its cavity presents an oval or nearly circular outline with walls about three times as thick as those of the right ventricle (fig. 661). It takes part in the formation of the sternocostal and left surfaces of the heart and is separated from the mediastinal surface of the left lung by the pericardium, the left phrenic nerve and pericardiophrenic vessels, and the left pleura. Inferiorly, it forms a large part of the diaphragmatic surface of the heart, and, anteriorly and to the left, it is separated from the right ventricle by the ventricular septum.

The *interior of the left ventricle* (figs. 657, 663) presents several important features for examination:

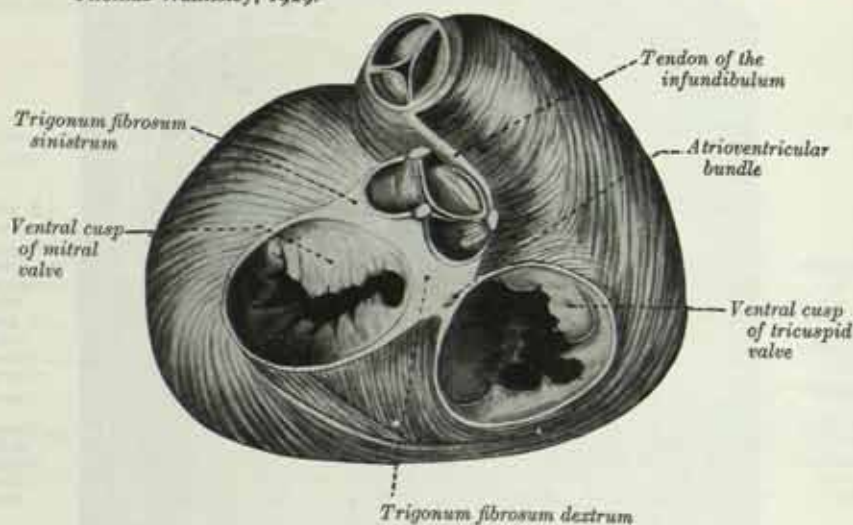
The *left atrioventricular or mitral orifice* is placed below and to the left of the aortic orifice. It is smaller than the right atrioventricular orifice, admitting the tips of two or three fingers. It is surrounded by a dense, fibrous ring and is guarded by the left atrioventricular or mitral valve.

The *aortic orifice* is a circular aperture in front and to the right of the left atrio-ventricular orifice, from which it is separated by the anterior cusp of the mitral valve. Its orifice has a diameter of a little over 2.5 cm., and is guarded by the aortic valve. The portion of the ventricle immediately below the aortic orifice is termed the *aortic vestibule*, and possesses fibrous instead of muscular walls.

The *left atrioventricular* or *mitral valve* (figs. 657, 665) is attached to the fibrous ring which encircles the left atrioventricular orifice. It consists of two triangular cusps, formed by duplications of the endocardium, strengthened by fibrous tissue and containing a few muscular fibres. The cusps are of unequal size, and are larger, thicker and stronger than those of the tricuspid valve. The larger cusp is placed in front and to the right between the atrioventricular and aortic orifices, and is known as the *anterior cusp*. Nearly all the chordæ tendineæ which reach it are attached near the margin of this cusp which is, therefore, smooth on both its surfaces. The smaller or *posterior cusp* is placed behind and to the left of the opening. Two small cusps are usually found in the angles between the larger cusps. The cusps of the mitral valve are furnished with chordæ tendineæ, which are attached in a manner similar to those on the right side of the heart; they are, however, thicker, stronger and less numerous.

As the blood flows from the atrium to the ventricle the cusps of the atrioventricular valve float upwards towards the orifice and, as the ventricular muscle contracts

FIG. 665.—The base of the ventricles, after removal of the atria and the pericardium. From Quain's *Elements of Anatomy*, vol. iv, part iii. *The Heart*, by Professor Thomas Walmsley, 1929.



they are prevented from passing into the atrium by the pull of the papillary muscles which enables them to resist the force exerted by the outflowing stream. Exploration of the interior of the left atrium at operations has shown that the larger anterior cusp billows up so as to present a convex surface to the examining finger during ventricular systole.* The anterior cusp measures 15–18 mm. in length while the posterior cusp has an average length of 10–12 mm. so that when the valve is closed there must be an appreciable degree of overlapping. This helps to ensure its competence as it covers the points where the tension is believed to be greatest.

The *aortic valve* (figs. 662, 669) consists of three semilunar segments or valvules which surround the orifice of the aorta; two are posterior (right and left), and one anterior. They are similar in structure, and in their mode of attachment, to the valvules of the pulmonary valve, but are larger, thicker and stronger; the lunulae are more distinct, and the nodules thicker and more prominent (fig. 669). Opposite the valvules the aorta presents three slight dilatations, termed the *aortic sinuses*, which are larger than those at the origin of the pulmonary trunk.

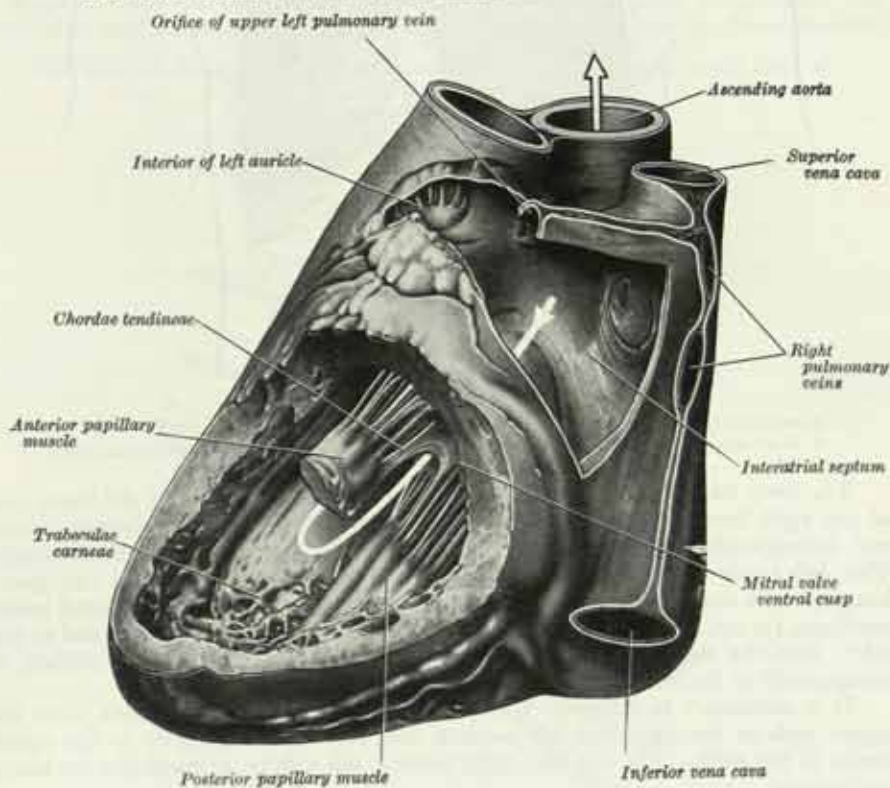
The *trabeculae carneae* are of three kinds, like those in the right ventricle, but they are more numerous, and present a dense interlacement, especially at the apex and upon the posterior wall of the ventricle. The *papillary muscles* are two in

* Sir Russell Brock, *Guy's Hosp., Rep.*, 104, 1955.

number, one (anterior) springing from the sternocostal, the other (posterior) from the diaphragmatic wall; they are of large size, and end in rounded extremities, from which the chordæ tendineæ arise. Chordæ tendineæ from each papillary muscle are attached to both cusps of the mitral valve.

The ventricular septum.—The right ventricle is separated from the left by the *ventricular septum* (figs. 657, 669), which slopes obliquely from before backwards and towards the right, and is curved with the convexity towards the right ventricle (fig. 661); its margins correspond with the anterior and posterior inter-ventricular grooves on the surface of the heart. The greater portion of the septum is thick and muscular; in its upper part, just below the junction of the anterior and right cusps of the aortic valve, there is a thin, fibrous area, which is termed the *membranous part of the ventricular septum* (fig. 657). This part of the septum is small in extent and oval in outline. On its right side it is crossed near its centre by the upper part of the attached border of the medial cusp of the tricuspid valve, which divides it into anterior and posterior portions. The anterior part separates the two ventricles from each other and may occasionally be congenitally defective (p. 166); the posterior part intervenes between the aortic vestibule of the left

FIG. 666.—A dissection to show the interior of the left side of the heart.



Note.—The large white arrow indicates the course taken by the blood in passing from the left atrium through the left ventricle to the aorta.

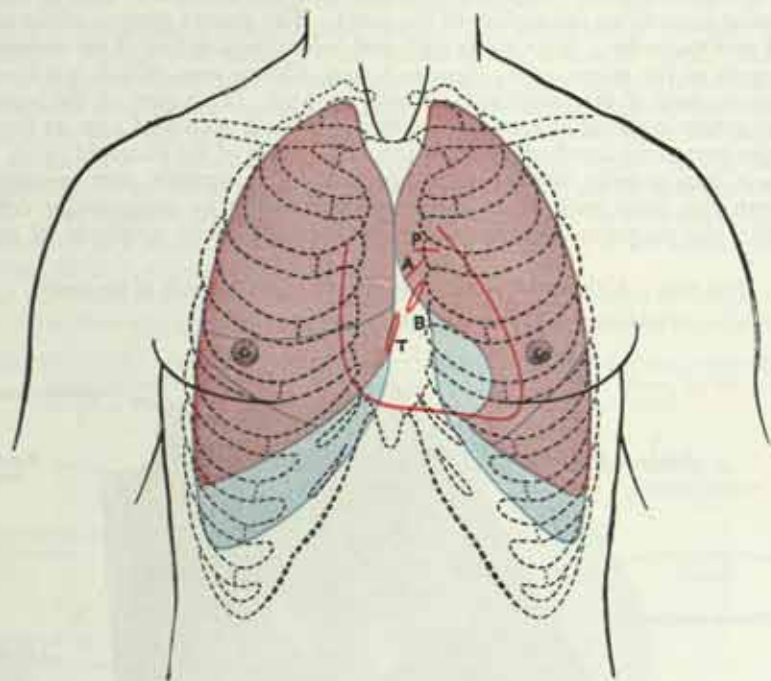
ventricle and the right atrium near the anterior horn of the limbus fossæ ovalis (p. 165). Superiorly, the membranous part of the ventricular septum can be traced into the trigonum fibrosum dextrum.

Surface marking of the heart.—The apex of the heart corresponds in position to the *apex beat*, which can usually be seen and can always be felt a little below and medial to the left nipple. As a rule it will be found in the fifth intercostal space, 9 cms. from the median plane.

The sternocostal surface of the heart can be projected on to the anterior chest-wall and forms an irregular, quadrangular area. The *right border* (fig. 667) corresponds to a line drawn from the upper border of the right third costal cartilage, 1.2 cm. from the margin of the sternum, downwards to the sixth costal cartilage.

This line is gently convex to the right and is at its maximum distance from the median plane—3.7 cm.—in the fourth intercostal space. It represents the lateral aspect of the right atrium. The continuation of this line in an upward direction marks the lateral border of the superior vena cava and, in a downward direction, the lateral border of the inferior vena cava.

FIG. 667.—The front of the thorax, showing the surface relations of the bones, lungs (purple), pleurae (blue), and heart (red outline).



A. = Orifice of aorta.
B. = Left atrio-ventricular (mitral) orifice.

P. = Orifice of pulmonary trunk.
T. = Right atrio-ventricular (tricuspid) orifice.

The *lower border* of the heart can be represented by a line joining the lower end of the right border to the apex-beat; it passes through the xiphisternal joint, and corresponds for the most part to the lower margin of the right ventricle. The *left border* of the heart is represented by a line drawn from the apex-beat upwards and medially to a point on the lower border of the left second costal cartilage, 1.2 cm. from the sternal margin. This line is convex upwards and to the left; with the exception of its upper part, which demarcates the left auricle, it corresponds to the left ventricle.

It is customary to complete the quadrangular area by a line which joins the upper ends of the right and left borders, and corresponds roughly to the upper limits of the atria. The left and right borders can also be mapped out by heavy percussion.

The *pulmonary orifice* (fig. 667) lies partly behind the upper border of the left third costal cartilage and partly behind the sternum. It can be represented by a horizontal line, 2.5 cm. long. Two parallel lines, drawn from the extremities of this line upwards and slightly to the left to reach the second costal cartilage, map out the *pulmonary trunk*.

The *aortic orifice* (fig. 667) lies below and a little to the right of the pulmonary orifice. It corresponds to a line, 2.5 cm. long, drawn from the medial end of the left third intercostal space downwards and to the right. Two parallel lines, drawn from the extremities of this line upwards and to the right as far as the right half of the sternal angle, outline the *ascending aorta*.

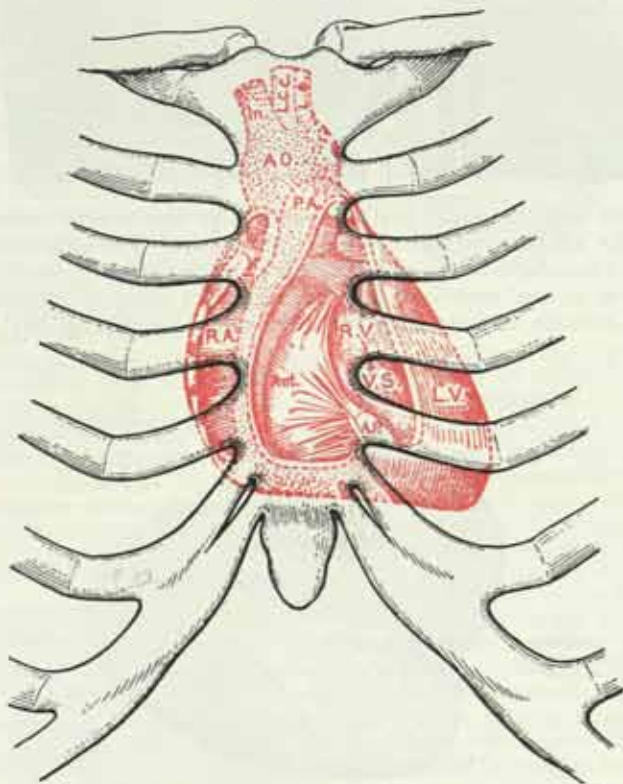
The *right atrioventricular, or tricuspid, orifice* (fig. 667) can be represented by a line, 4 cm. long, commencing in the median plane opposite the fourth costal cartilage, and passing downwards and slightly to the right. The centre of this line

should be opposite the middle of the fourth intercostal space. The *left atrio-ventricular*, or *mitral*, *orifice* lies behind the left half of the sternum opposite the fourth costal cartilage and can be represented by a line, 3 cm. long, passing downwards and to the right.

The *area of superficial cardiac dulness* is a roughly triangular area, which can be mapped out by light percussion, and corresponds to the portion of the heart which is not covered with lung.

Radiological appearance of the heart (Pl. XIX).—The heart, being full of blood, casts a shadow, occupying the lower part of the mediastinum, which is in sharp contrast with the clearer areas occupied by the air-filled lungs. The expansile movements of this shadow are evident on screening. In full inspiration the shadow of the apex is clear of the diaphragm, and presents, in radiographs, a rather blurred outline due to its movement. The shadow of the convex right border of the heart is continuous above with that of the superior vena cava and below with that of the inferior vena cava. In lateral radiographs the *retrocardiac space* may be recognised as a translucent area between the heart and the vertebral column. This space is occupied by the descending aorta and the œsophagus (Pl. XX). For a detailed study of the cavities of the heart and the large bloodvessels the method of *angiocardiology* * can be used. A suitable contrast medium miscible

FIG. 668.—A diagram showing the relations of the opened heart to the front of the thoracic wall.



Ant. Anterior segment of tricuspid valve. AO. Aorta. A.P. Anterior papillary muscle. In. Brachiocephalic (Innominate) artery. L.C.C. Left common carotid artery. L.S. Left subclavian artery. L.V. Left ventricle. P.T. Pulmonary trunk. R.A. Right atrium. R.V. Right ventricle. V.S. Ventricular septum.

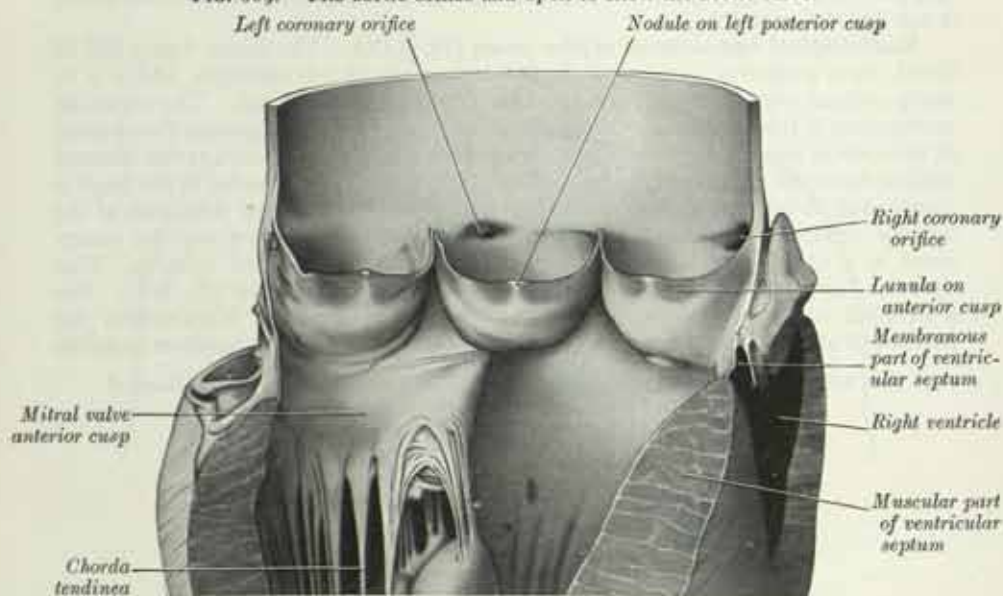
with the blood is injected intravenously and the course of the intravascular injection is followed in serial X-ray exposures in anteroposterior or oblique views (Pl. XX, A).

Structure.—The heart consists of muscular fibres (*myocardium*) and of fibrous rings which serve partly for their attachment. It is covered with the visceral layer of the serous pericardium (*epicardium*), and lined with the *endocardium*.

* Robb and Steinberg (1939) *Amer. J. Roent.*, 51, 33 and F. Gardner, *Postgraduate Med. J.*, 25, 1949.

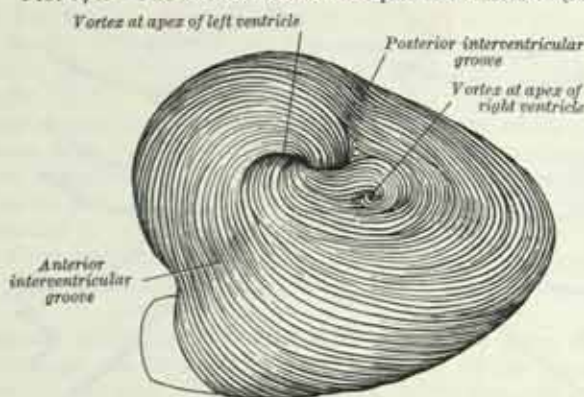
The *endocardium* is a thin, smooth, glistening membrane which lines the chambers of the heart, and is continuous with the lining membrane of the large blood-vessels; by its reduplications it assists in forming the valves. It consists of a layer of endothelial cells placed on a stratum of connective tissue and elastic fibres.

FIG. 669.—The aortic orifice laid open to show the aortic valve.



The *fibrous rings* surround the atrioventricular and arterial orifices, and are stronger on the left than on the right side of the heart. The atrioventricular rings serve for the attachment of the muscular fibres of the atria and ventricles, and for the attachment of the atrioventricular valves. The interval between the aortic arterial ring, in front, and the atrioventricular rings, behind (fig. 665), is occupied

FIG. 670.—The two vortices at the apex of the heart. (Mall.)



by a tough mass of fibrous tissue, which represents the *os cordis* of some of the larger mammals and is termed the *trigonum fibrosum dextrum*. A similar, but smaller, mass of fibrous tissue, termed the *trigonum fibrosum sinistrum*, lies between the left side of the aortic arterial ring and the front of the left atrioventricular ring. The tendon of the infundibulum has already been mentioned (p. 710).

The fibrous rings surrounding the arterial orifices serve for the attachment of the great vessels and their valves. Each ring receives, by its ventricular margin, the attachment of some of the muscular fibres of the ventricles; its opposite margin presents three deep, semicircular notches, to which the middle coat of the artery is firmly fixed. The attachment of an artery to its fibrous ring is strengthened by the external coat of the artery and the epicardium externally, and by the endocardium

internally. From the margins of the semicircular notches the fibrous structure of the ring is continued into the semilunar valvules. The middle coat of the artery in this situation is thin, and the vessel is dilated to form the sinuses of the aorta and pulmonary trunk.

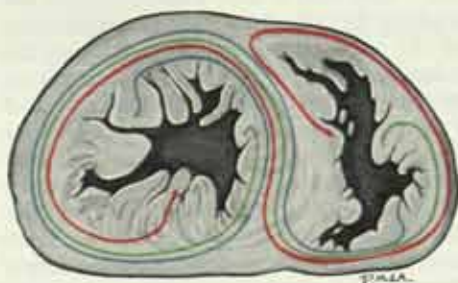
The *muscular structure of the heart* consists of fibres which are transversely and longitudinally striated (p. 36), and present an exceedingly intricate interlacement. They comprise (a) the fibres of the atria, (b) the fibres of the ventricles and (c) the atrioventricular bundle.

The *fibres of the atria* are arranged in two layers—a superficial, common to both atria, and a deep, proper to each. The *superficial fibres* are most distinct on the front of the atria, across the bases of which they run in a transverse direction, forming a thin and incomplete layer; some of them pass into the interatrial septum. The *deep fibres* consist of looped and annular fibres. The *looped fibres* pass upwards over each atrium, and are attached by their extremities to the corresponding atrioventricular ring, in front and behind; the *annular fibres* surround the auricles, and form annular bands around the terminations of the veins and around the fossa ovalis.

The *fibres of the ventricles* are arranged in a complex manner, and various accounts have been given of their course and connexions; the following description is based on that given by MacCallum.* They consist of superficial and deep layers, all of which, with the exception of two, are inserted into the papillary muscles of the ventricles. It is important to remember that in the infundibulum the

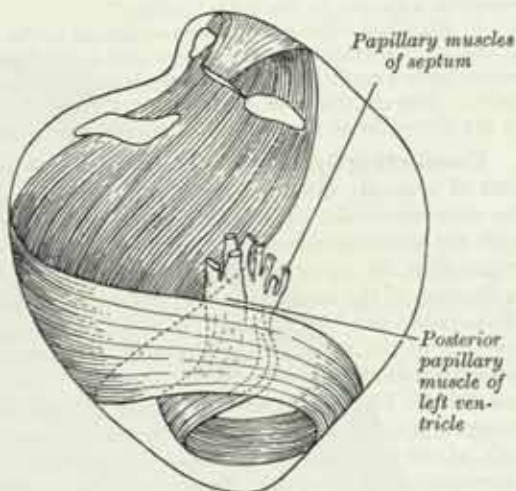
superficial fibres run transversely to its long axis, but the deep fibres are almost vertical in their direction. On this account when the infundibulum is opened at operation, a vertical incision should always be employed. The *superficial layers* comprise the following: (a) Fibres which spring from the tendon of the infundibulum (p. 710) and pass across the diaphragmatic surface; they curve round the lower border of the

FIG. 672.—A diagram of the arrangement of the deep layers of the muscular fibres of the ventricles, as seen in a cross-section of the ventricles. (Based on MacCallum's description.)



heart and sweep towards the left across the anterior interventricular groove and around the apex of the heart, where they form a vortex (fig. 670) and pass upwards and inwards to terminate in the papillary muscles of the left ventricle; those arising from the upper (anterior) half of the tendon of the infundibulum pass to the posterior and septal papillary muscles, those from the lower (posterior) half to the anterior papillary muscle; (b) Fibres which arise from the right atrioventricular ring and run diagonally across the diaphragmatic surface of the right ventricle and round its lower border on to its sternocostal surface. There they dip beneath the fibres just described, and, crossing the anterior interventricular groove, wind around the apex of the heart and end in the posterior papillary muscle of the left ventricle. (c) Fibres which spring from the left atrioventricular ring, and, crossing the posterior interventricular groove, pass successively into the right ventricle and end in its papillary muscles. The *deep layers* are three in number; they arise in the papillary muscles of one ventricle and, curving in an S-shaped manner, turn in at the interventricular groove and end in the papillary muscles of the other

FIG. 671.—A diagram of the superficial muscular fibres of the ventricles of the heart originating in the tendon of the infundibulum. (After MacCallum.)



* John Bruce MacCallum, *Johns Hopkins Hosp. Bull.*, 9, 1897.

ventricle (fig. 672). The layer which is most superficial in the right ventricle lies next the lumen of the left, and vice versa. Those of the first layer almost encircle the right ventricle and, crossing in the septum to the left ventricle, unite with the superficial fibres from the right atrioventricular ring to form the posterior papillary muscle. Those of the second layer have a less extensive course in the wall of the right ventricle and a correspondingly greater course in the left, where they join with the superficial fibres from the upper half of the tendon of the infundibulum to form the papillary muscles of the septum. Those of the third layer pass almost entirely round the left ventricle and unite with the superficial fibres from the lower half of the tendon of the infundibulum to form the anterior papillary muscle. The arrangement of these three layers ensures the synchronisation of ventricular systole and the closure of the atrioventricular valves. Besides the layers just described there are two bands which do not end in papillary muscles. One springs from the right atrioventricular ring, crosses in the atrioventricular septum, encircles the deep layers of the left ventricle and ends in the left atrioventricular ring. The second band is apparently confined to the left ventricle; it is attached to the left atrioventricular ring and encircles the portion of the ventricle adjacent to the aortic orifice.*

A. Blackhall-Morison † draws attention to the existence of a set of fibres belonging to the left ventricular musculature and to the lower segment of the left atrium, and which have a triple insertion into the base of the aorta, close to the valves of the aortic valve. The effect of the contraction of these fibres "is to rotate the base of the aorta in the direction of the general ventricular twist in systole".

Conducting System of the Heart. ‡—The conducting system of the heart consists of specially differentiated cardiac muscle. It comprises the sinu-atrial node, the atrioventricular node, the atrioventricular bundle and its two fasciculi together with the subendocardial plexuses of Purkinje fibres in which they terminate. It is responsible for maintaining the normal cardiac rhythm and ensures the proper co-ordination of the atrial and ventricular contractions. The *sinu-atrial node*, which is often called the 'pacemaker' of the heart, is situated on the right border of the opening of the superior vena cava in the upper part of the sulcus terminalis and extends medially in front of the opening. It is covered only with the epicardium and a little fat, and in sections made at right angles to the sulcus terminalis it is wedge-shaped, the base of the wedge being directed to the endocardium. The main bulk of the node lies on the sinus venosus side of the crista terminalis. The *atrioventricular node* lies above the orifice of the coronary sinus in the annular and septal fibres of the right atrium. Both nodes are similar in general plan and consist of a meshwork of specialised cardiac muscle fibres which are narrower and finer than any other fibres in the heart-wall. They are completely cross-striated and frequently branch. The fibres of the sinu-atrial node are slightly narrower but are longer than the fibres of the atrioventricular node. They are more loosely arranged and are fusiform in shape, whereas the fibres of the atrioventricular node are cylindrical and the meshwork which they form is more compact. No direct connexion between the two nodes has been demonstrated, but the branching fibres of both are directly continuous with the fibres of the right atrium and it is generally believed that the impulse, which originates at the sinu-atrial node, travels by this pathway to reach the atrioventricular node. Very few, if any, Purkinje fibres are present in the wall of the right atrium but where they do occur they are continuous on the one hand with nodal fibres and on the other with atrial fibres. From the atrioventricular node the *atrioventricular bundle* passes upwards in the trigonum fibrosum dextrum until it reaches the posterior margin of the membranous part of the ventricular septum, and then turns forwards below it. In this situation it divides into right and left fasciculi which straddle the muscular septum. These run down in the right and left ventricles, one on each side of the ventricular septum. The right fasciculus, after passing towards the apex embedded in the muscle of the right surface of the ventricular septum, enters the septomarginal trabecula (moderator band) and so reaches the base of the anterior papillary muscle. In this situation it forms a subendocardial plexus of Purkinje fibres which are distributed to the papillary muscles and walls of the right ventricle. The left fasciculus consists of two main strands, an anterior and a posterior, which pass towards the apex immediately beneath the endocardium covering the left surface of the ventricular septum.

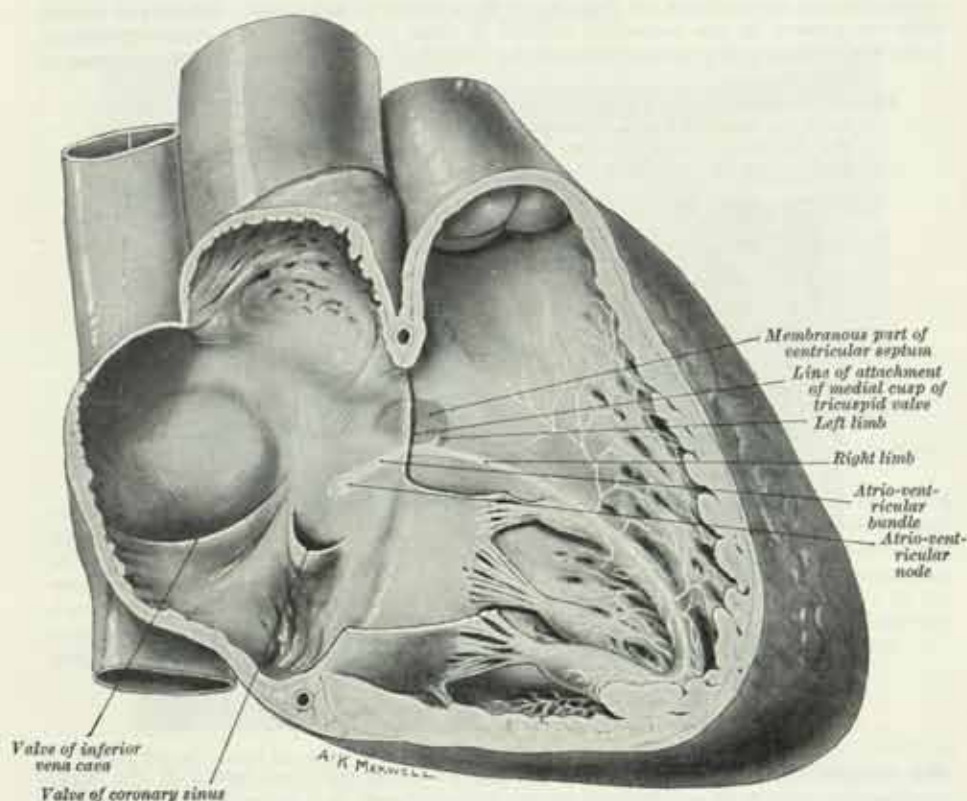
* Franklin P. Mall, "On the Muscular Architecture of the Ventricles of the Human Heart," *American Journal of Anatomy*, vols. 11 and 13.

† *Edinburgh Medical Journal*, New Series, vol. xxx, No. 9, September 1923.

‡ D. M. Blair and F. Davies, *J. Anat.*, 69, 1935.

Having traversed the trabeculae carneae they reach the papillary muscles and terminate in the same manner as the right fasciculus. The fibres of the bundle and the fasciculi are slightly thicker ($9\ \mu$) than the fibres of the atrioventricular node ($7\ \mu$) and exhibit transverse striations throughout their whole thickness except for a small clear perinuclear area. In the human heart, they are almost indistinguishable from the ordinary ventricular muscle fibres. In the ox the atrioventricular bundle and its divisions are enveloped in a sheath of connective tissue; by injecting this sheath with Indian ink the ramifications of the bundle can be demonstrated. In the human heart the sheath is not well developed; it surrounds the bundle but not the fasciculi.

FIG. 673.—A schematic representation of the atrioventricular bundle, its right limb and the Purkinje plexus.



Portions of the walls of the right atrium and ventricle have been removed and a part of the medial cusp of the tricuspid valve has been excised.

The hearts of cold-blooded vertebrates beat more slowly in proportion to their size than do the hearts of birds and mammals, and it is to be noted that they do not possess a special conducting system.* The rate of conduction in normal heart muscle is too slow to meet the needs of warm-blooded vertebrates and the conducting system may be regarded as a provision to meet the demands made by their higher metabolic rates, for the conductivity of the fibres of the atrioventricular bundle is much higher than that of ordinary cardiac muscle. It is essential, however, that the impulse should not travel too rapidly from the sinu-atrial node to the ventricular muscle, as sufficient time must be allowed to enable the atria to fill the ventricles. The necessary delay is imposed on the impulse by its passage through the atrioventricular node.

It has long been known that, when perfused with a solution containing certain inorganic salts in proper proportions, the heart of either a cold- or a warm-blooded animal will continue to beat rhythmically for a long time after its nervous and

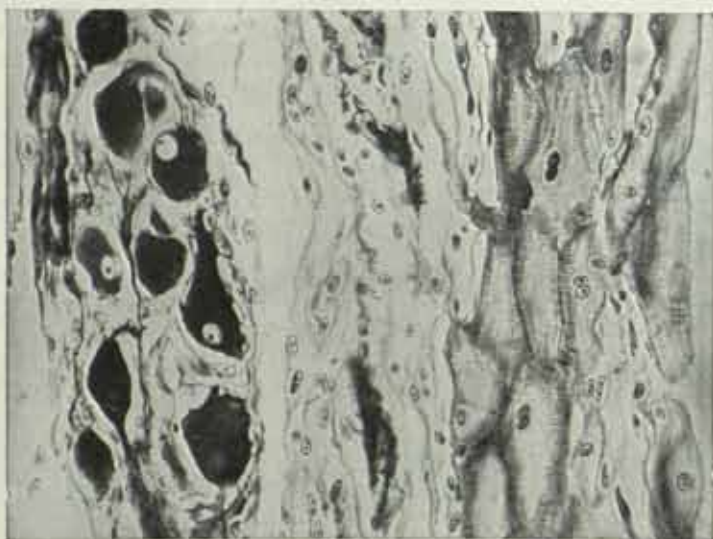
* "The Conducting System of the Vertebrate Heart," F. Davies and E. B. T. Francis, *Biol. Rev.*, 21, 1946.

vascular connexions have been severed completely. Many explanations have been suggested to account for this inherent rhythmicity but none can be regarded as completely satisfactory.

At the same time it should be noted that each chamber of the heart has its own intrinsic rhythmic rate. In the salamander,* for example, the sinus venosus rate is 50, the atrial rate is 14, and the ventricular rate is 7 per minute. Nodal tissue has a higher rhythmicity than ordinary heart muscle and determines the rate of the heart in birds and mammals. When the atrioventricular bundle is interrupted completely (the condition known as 'total heart-block' in man), the ventricles take on their own intrinsic rhythmic rate and beat much more slowly than the atria, which remain under the influence of the sinu-atrial node.

In the human heart groups of nerve cells are situated in the immediate neighbourhood of the sinu-atrial node, especially on the epicardial side, and numerous unmyelinated nerve-fibres are distributed throughout its substance. Groups of nerve-cells are present in the interatrial septum in close proximity to the atrio-ventricular node but relatively few nerve-fibres can be identified in the node itself. In contrast to

FIG. 674.—Longitudinal section of the left fasciculus of the atrioventricular bundle from the heart of a cow. $\times 260$. Note the incomplete striation of the cells of the fasciculus (right portion of figure). Drawn from a micro-photograph kindly lent by Professors D. M. Blair and Francis Davies.



the condition in many mammals (fig. 674) no nerve-cells are found in the atrio-ventricular bundle or its fasciculi in the human heart, but nerve-fibres are present running in very small parallel bundles or sometimes even as individual fibres.

A. Blackhall-Morison† has shown that in the sheep and pig the atrioventricular bundle "is a great avenue for the transmission of nerves from the auricular to the ventricular heart"; large and numerous nerve-trunks enter the bundle and course with it. Branches arise from these nerve-trunks and form plexuses around groups of Purkinje cells, and from these plexuses fine fibrils go to innervate individual cells.

The sinu-atrial and atrioventricular nodes, the atrioventricular bundle and its right fasciculus, are supplied by the right coronary artery; the left fasciculus of the bundle is supplied by both coronary arteries. The artery to the sinu-atrial node ascends in the sulcus terminalis and, within the node itself, it is encircled by nodal fibres. There is no corresponding nodal vein.

Vessels and Nerves.—The arteries supplying the heart are the right and left coronary branches of the aorta (p. 730); the majority of the veins are drained by the coronary sinus into the right atrium.

The lymph vessels are described on p. 911.

The nerves are derived from the cardiac plexus (p. 1214), which is formed by branches from the vagi and sympathetic. They are freely distributed both on the

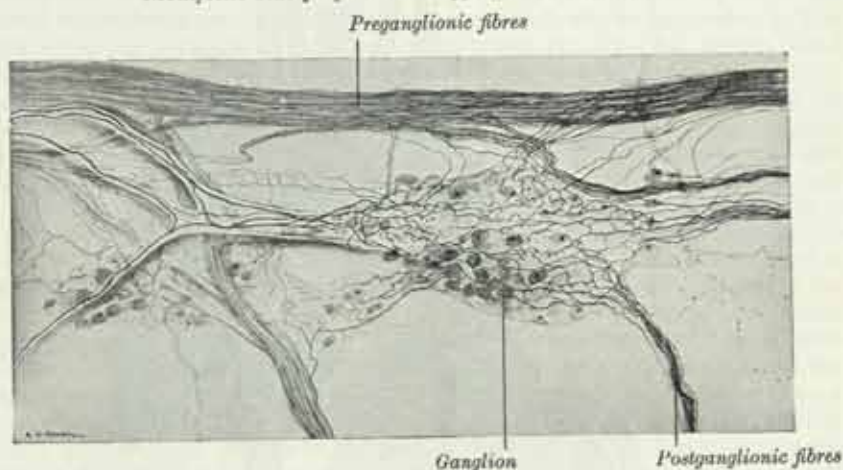
* Davies, F., and Francis, E. T. B., *Phil. Trans. Roy. Soc.*, B. No. 578, 231, 99. 1941.

† *J. Anat. and Phys.*, 46, 1912.

surface and in the substance of the heart, the separate nerve-filaments being furnished with small ganglia. The atrioventricular bundle receives nerve-fibres from ganglia in the interatrial septum. Other ganglia are found in relation with the sinoatrial node, and supply it with nerve-filaments.

H. H. Woollard (*J. Anat.*, 60, 1926) has investigated, by the methylene-blue method, the distribution of the cardiac nerves in the dog, cat, rabbit and guinea-pig. His chief conclusions are: 1. In the intracardiac ganglia the types of cell, though varying in the disposition of the dendrites and in the mode of the ending of the preganglionic fibres, all belong to the parasympathetic (fig. 675). 2. There is some evidence to show that the atria and the atrioventricular bundle are supplied by parasympathetic and sympathetic fibres, while the ventricular muscle is supplied by

FIG. 675.—Nerves and ganglia from the posterior surface of the left atrium of a dog. Methylene blue preparation. $\times 55$. H. H. Woollard.



sympathetic fibres only. 3. The fibres spin a plexus about the muscle-cell, and ultimately enter the protoplasm of the muscle and run in the protoplasmic connexions of the muscle; small endings, often perinuclear in position, are given off inside the muscle-cell. 4. The valves, the subendocardial and the subepicardial tissues are innervated by a very fine plexus of nerves which, for the most part, belongs to the sympathetic system. 5. The larger branches of the coronary arteries are predominantly innervated by sympathetic, the finer branches by parasympathetic, fibres.

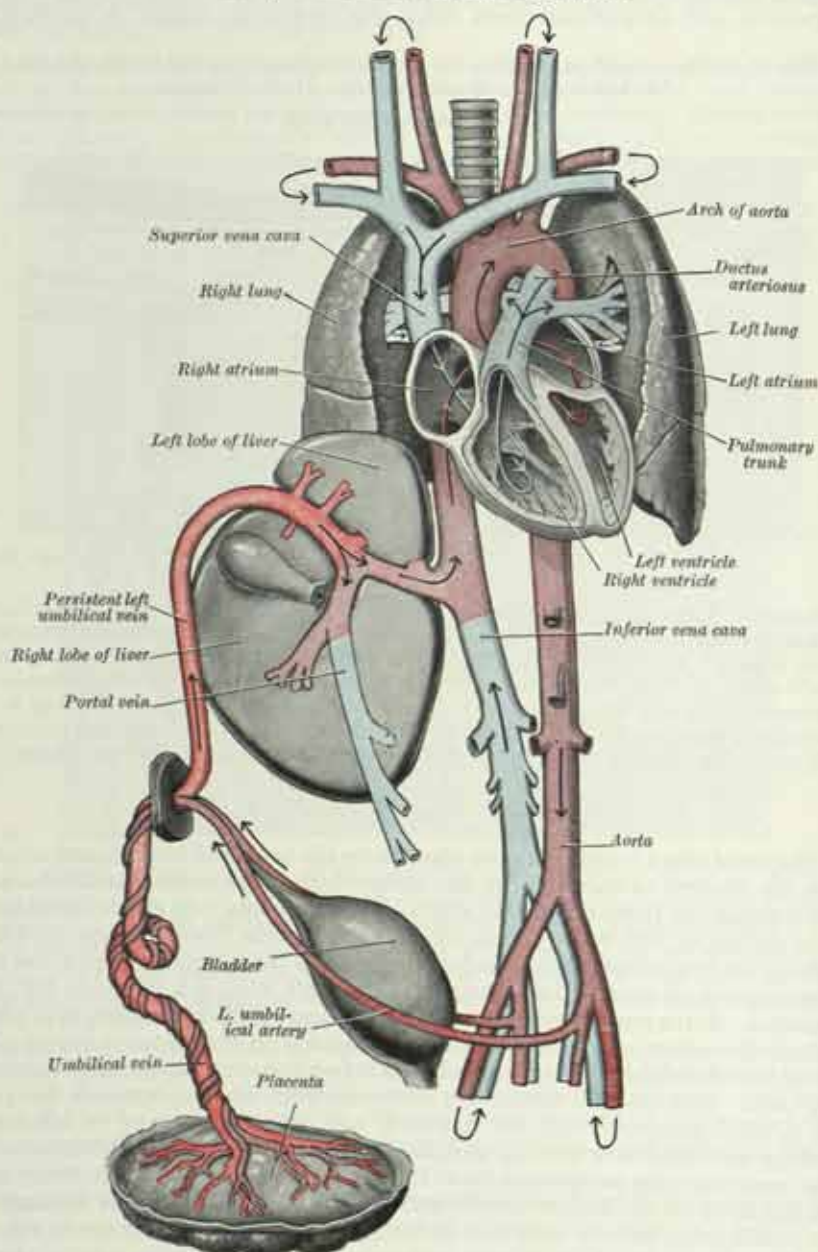
THE FŒTAL CIRCULATION (fig. 676)

The fetal blood is carried to the placenta by the umbilical arteries, and returned from the placenta to the fetus by two veins which unite in the umbilical cord to form a single vein (vena umbilicalis impar). The umbilical vein enters the abdomen at the umbilicus, and its persistent left branch (its right branch having atrophied) passes in the free margin of the falciform ligament to the visceral surface of the liver, where it gives off two or three branches to the left lobe, and others to the lobus quadratus. At the porta hepatis it joins the left branch of the portal vein, from which, opposite this point, a large vessel arises and ascends on the posterior aspect of the liver to join the left hepatic vein immediately before that vessel opens into the inferior vena cava. This vessel is termed the *ductus venosus*. During fetal life the portal vein is small compared with the umbilical vein, and the parts of its left branch proximal and distal to where the umbilical vein joins it function as branches of the latter vessel carrying oxygenated blood to the right and left parts respectively of the liver (fig. 676). It will be seen therefore that the blood conveyed by the left umbilical vein passes to the inferior vena cava in three different ways. Some enters the liver directly and is carried to the inferior vena cava by the hepatic veins; a considerable quantity circulates through the liver with the portal venous blood, before entering the inferior vena cava by the hepatic veins; the remainder passes into the inferior vena cava through the ductus venosus.

In the inferior vena cava, the blood carried by the ductus venosus and hepatic veins mixes with that returning from the lower limbs and from the abdominal wall.

It enters the right atrium, and, guided by the valve of the inferior vena cava, passes for the most part through the *foramen ovale* into the left atrium, where it mingles with a small quantity of blood returned from the lungs by the pulmonary veins. A small amount of blood returned to the heart by the inferior vena cava, however, instead of passing through the foramen ovale, goes through the right atrioventricular orifice with the blood from the superior vena cava. From the left atrium blood passes into the left ventricle, and from that cavity into the aorta, through the

FIG. 676.—A plan of the fetal circulation.



In this plan the arrows represent the course which the blood takes in the heart and vessels.

branches of which it is probably distributed almost entirely to the heart itself and to the head and the upper limbs, only a small quantity being carried into the descending aorta. The blood from the head and the upper limbs is returned by the

superior vena cava to the right atrium and all of it passes through the right atrio-ventricular orifice, carrying with it a small amount of the blood returned by the inferior vena cava. Having reached the right ventricle this blood passes into the pulmonary trunk. The lungs of the foetus being inactive, only a small quantity of the blood conveyed by the pulmonary trunk is distributed to them by the right and left pulmonary arteries, and returned by the pulmonary veins to the left atrium; the greater part passes through the *ductus arteriosus* into the aorta, where it mixes with the small quantity of blood transmitted by the left ventricle into this part of the aorta. It descends through the aorta and is in part distributed to the lower limbs and to the viscera of the abdomen and pelvis, but most of it is conveyed by the umbilical arteries to the placenta.

The preceding account of the circulation of the blood in the foetus has been confirmed by observations made by radiography after the injection of radio-opaque substances into the bloodstream in foetal sheep.* The following facts, which are supported by evidence provided by blood-gas analysis,† will be inferred: 1. The placenta serves the purposes of nutrition and excretion, receiving the impure blood from the foetus and returning it purified and charged with nutritive material. 2. Some of the blood of the left umbilical vein traverses the liver before entering the inferior vena cava; this is correlated with the relatively large size of the liver, especially at an early period of foetal life. 3. Only the pulmonary veins open directly into the left atrium, and the volume of blood which enters it from this source is very small. On the other hand, the volume of the blood entering the right atrium is much greater, and the pressure within that chamber is much higher than the pressure in the left atrium. As a result, the flap-like septum primum (p. 161) is thrust over to the left (fig. 176, D) and the passage of blood from the right to the left side of the heart is effected easily. The valve of the inferior vena cava is placed so as to enable it to direct nearly all the blood which issues from that vessel to the foramen ovale and so to the left atrium, whereas the blood entering the right atrium from the superior vena cava passes directly into the right ventricle. 4. The pure blood carried from the placenta to the foetus, mixed with the blood from the portal vein and inferior vena cava, passes almost directly to the arch of the aorta, and is distributed by the branches of that vessel to the head and the upper limbs. 5. The blood contained in the descending aorta, chiefly derived from that which has already circulated through the head and the upper limbs, together with a small quantity from the left ventricle, is distributed to the abdomen and the lower limbs.

THE CHANGES IN THE VASCULAR SYSTEM AT BIRTH

At birth, when respiration is established, an increased amount of blood from the pulmonary trunk passes through the pulmonary arteries to the lungs, and a correspondingly increased amount returns by the pulmonary veins to the left atrium. The pressures within the two atria become equalised, and the foramen ovale, which is valve-like in character, is closed by the apposition, and later by the fusion, of the septum primum to the septum secundum (fig. 176).‡ Not infrequently the fusion is incomplete and a communication between the two atria may persist throughout life. Such a communication, unless large, has no functional significance as, owing to the equality of the intra-atrial pressures and the valve-like arrangement of the opening, no blood can pass from one side to the other.

When the umbilical cord is ligatured and the placental circulation is cut off, the umbilical vein becomes thrombosed and is gradually converted into a fibrous cord which constitutes the *ligamentum teres* of the liver. The ductus venosus also becomes obliterated, but the reasons for its obliteration are not so obvious and may possibly be associated with the alteration in the position of the liver brought about by the establishment of the respiratory movements. Its fibrous remnant is found in the adult as the *ligamentum venosum* of the liver.

Obliteration of the ductus arteriosus is an essential but, probably, a gradual

* "The Foetal Circulation," A. E. Barclay, K. J. Franklin, M. M. L. Prichard (Blackwell, 1944).

† Huggett, *J. Physiol.*, 62, pp. 373-384.

‡ It is possible that contraction of the muscle of the septum primum synchronised with contraction of the muscle in the wall of the superior vena cava may play a part in this closure which probably occurs some considerable time after the functional closure of the ductus arteriosus described below (A. E. Barclay and K. J. Franklin, *Journ. Physiol.*, 94, 256-258).

process, associated with proliferation of the lining endothelium and taking some months to complete. Functional closure, on the other hand, occurs very soon after birth and results from the reflex contraction of the thick muscular wall of the vessel.*

Before birth the vessel is the direct continuation of the pulmonary trunk, and has a similar calibre. Ultimately it forms an impervious cord which connects the left pulmonary artery near its origin with the arch of the aorta and is termed the *ligamentum arteriosum*. Following ligation of the umbilical cord, the umbilical or hypogastric arteries become thrombosed from the point at which they give off their last branches—the superior vesical arteries—to the umbilicus, and are subsequently converted into fibrous cords, which lie in the extraperitoneal fatty tissue of the lower part of the anterior abdominal wall and produce the *medial umbilical folds* of peritoneum.

ABNORMALITIES OF THE HEART

1. *Abnormalities of position.*

(a) The position of the heart may be completely reversed so that the apex is directed towards the right instead of the left. This condition is associated with mirror image positioning of the great vessels and of the aortic arch. It may be a part of general transposition of the viscera or 'situs inversus' or the condition may affect only the heart.

(b) *Ectopia cordis*. The heart may project on the surface of the thorax through a gap in the lower part of the chest wall. This is associated with a breakdown of the thin body wall and anterior part of the pericardium at a very early stage of development.

2. *Abnormalities due to failure of development or to incomplete absorption.*

Probably the great majority of serious cardiac deformities result from these causes, the commonest failure affecting the bulbus cordis and the absorption of the bulbo-ventricular ridge (p. 155). If the bulbo-ventricular ridge is not properly absorbed the truncus lies in an abnormal position relative to the atrioventricular openings so that it is impossible for the bulbar septa to meet the interventricular septum and the septum intermedium in proper relationship and there is often a patent interventricular foramen. Moreover the relative position and size of the aortic and pulmonary orifices are usually altered, the aorta lying much further to the right and anteriorly and overriding the ventricular septum. Since it receives a larger share of the circulation than normal, the aortic part of the bulb and truncus undergoes abnormal enlargement relative to the pulmonary trunk which is often stenosed in these cases.

The following are some of the varieties of failure of development and incorporation :

(a) Failure of development of the bulbus.

(1) Severe arrest. This results in atresia of the pulmonary or aortic infundibulum, more often the former. There is extensive fibrosis where the pulmonary orifice should be. There is invariably an interventricular foramen and often a patent ductus arteriosus through which the pulmonary circulation is carried out. When the ductus does close, the bronchial arteries may enlarge to take blood to the lungs, but cyanosis is a prominent feature of all these cases. The name 'Fallot's tetralogy' is given to the condition where there is a combination of pulmonary stenosis or atresia, a displacement of the aortic opening to the right to override the ventricular septum, an interventricular defect and hypertrophy of the right ventricle.

(2) Failure of expansion of the bulb. This results commonly in pulmonary stenosis, more rarely in aortic stenosis. A fibrous ring usually separates the pulmonary infundibulum from the body of the ventricle, the pulmonary valvules may be fused in addition and there is usually an interventricular foramen. Another variety of pulmonary stenosis affects the valve only; the valvules are fused to form a conical diaphragm perforated at its centre by a small opening.

* Sir Joseph Barcroft, *Lancet*, vol. ii, 1941; A. E. Barclay, J. Barcroft, K. J. Franklin and D. H. Barron, *Brit. Journ. of Radiology*, 12, 1939; and A. E. Barclay, K. J. Franklin and M. M. L. Prichard, *Brit. Journ. of Radiology*, 15, 1942.

(b) Failure of incorporation of the sinus venosus into the right atrium (see p. 159) is rare.

(c) Failure of absorption of the pulmonary veins into the left atrium (p. 161) may occur. When complete, there is only one common pulmonary vein which receives four tributaries, two from each lung.

3. Defects of the cardiac septa.

(a) The interatrial septum. Any degree of defect may occur from complete absence of the septum to a persistent valvular foramen ovale, the latter being often of no functional significance. Severe defects where the foramen ovale primum has never closed are occasionally associated with one common atrioventricular orifice guarded by three cusps.

(b) The ventricular septum. Failure of the membranous septum to form is often associated with abnormalities in absorption or expansion of the bulb (see above). The ventricular septal defect may be relatively small and compatible with many years of normal life, or may be larger and of much graver significance. Displacement of the muscular septum to one or other side, usually the right, and incomplete growth of this septum may give the appearance of there being a single ventricle.

(c) The bulbar septum may be perforated or may fail to develop, in which case there is a common truncus from which the pulmonary arteries and the aorta arise.

(d) Transposition of the aorta and the pulmonary trunk. Reversal of the spiral aorto-pulmonary septum may occur in which case the aorta springs from the right and the pulmonary trunk from the left ventricle.

4. Abnormalities of the visceral arches.

(a) Right aortic arch (see p. 170).

(b) Patent ductus arteriosus (see p. 704).

(c) Coarctation of the aorta (see p. 794).

THE ARTERIES

The distribution of the systemic arteries is like a highly branched tree, the common trunk of which, formed by the aorta, commences at the left ventricle, while the smallest ramifications extend to the viscera and to the peripheral parts of the body. Arteries are found in all parts of the body, except in the hairs, nails, epidermis and corneæ. The larger trunks usually occupy protected situations, running, in the limbs, along the flexor surfaces, where they are less exposed to injury.

There is considerable variation in the mode of division of the arteries: occasionally a short trunk subdivides into several branches at the same point, as in the celiac and thyrocervical trunks; more usually the vessel gives off several branches in succession, and still continues as the main trunk, as in the arteries of the limbs.

A branch of an artery is smaller than the trunk from which it arises; but if an artery divides into two branches, the combined sectional area of the two vessels is, in nearly every instance, somewhat greater than that of the trunk; and the combined sectional area of all the arterial branches greatly exceeds that of the aorta.

Arteries do not always end in capillaries; in many cases they unite with one another, forming what are called *anastomoses*. Anastomosis between trunks of nearly equal size is found in the brain, where the two vertebral arteries unite to form the basilar artery, and the two anterior cerebral arteries are connected by the anterior communicating artery; and in the abdomen, where the intestinal arteries have free anastomoses between their larger branches. In the limbs, the anastomoses are largest and most numerous around the joints; the branches arising from an artery above a joint uniting with branches from the vessels below it. These anastomoses are of considerable interest to the surgeon, as it is by their enlargement that a *collateral circulation* is established after the application of a ligature to a main artery. From the practical point of view, the importance of any individual arterial anastomosis depends on the distance which separates the points of origin of the anastomosing vessels. The smaller branches of arteries anastomose more frequently than the larger; and between the smallest twigs these anastomoses may be so numerous that they constitute a close network. In certain regions of the body there are arteries which have no anastomoses with their neighbours and are therefore

called *end-arteries*. If an artery of this type be occluded, serious nutritional disturbances resulting in death (necrosis) will occur in the tissues supplied by the vessel. The central artery of the retina is the best example of an end-artery, and its occlusion is followed by permanent blindness. In the grey substance of the cerebral cortex the arteries communicate with one another only through the capillary bed and from the practical point of view they are end-arteries. The same applies to the arteries of the spleen, kidneys and lungs.

THE PULMONARY TRUNK

The **pulmonary trunk** (figs. 677, 680 and 1099) conveys deoxygenated blood from the right ventricle of the heart to the lungs. It is about 5 cm. in length and 3 cm. in diameter, and arises from the base of the right ventricle above and to the left of the supraventricular crest. It runs upwards and backwards, at first in front

FIG. 677.—A transverse section through the mediastinum at the level of the lower border of the fifth thoracic vertebra.



of the ascending aorta, and then to its left side. In the concavity of the aortic arch it divides, at the level of the fifth thoracic vertebra, into right and left pulmonary arteries, which are of nearly equal size.

Relations.—The whole of the pulmonary trunk is contained within the pericardium. Together with the ascending aorta it is enclosed in a common tube of the visceral layer of the serous pericardium. The fibrous layer of the pericardium is gradually lost upon the external coats of the two pulmonary arteries. *In front*, the pulmonary trunk is separated from the sternal end of the left second intercostal space by the pleura, the left lung and the pericardium. *Behind*, it rests at first upon the ascending aorta and the left coronary artery; at a higher level it lies in front of the left atrium, and the ascending aorta is on its right side. The auricle of the corresponding atrium and a coronary artery lie on each side of its origin. The superficial part of the cardiac plexus lies between the division of the pulmonary trunk and the arch of the aorta.

The **right pulmonary artery**, slightly longer and larger than the left, runs horizontally to the right, behind the ascending aorta, superior vena cava and upper right pulmonary vein, and in front of the œsophagus and the right bronchus, to the root of the right lung, where it divides into two branches. The lower and larger of these is distributed to the middle and lower lobes of the lung; the upper and smaller accompanies the upper right lobar bronchus.

The **left pulmonary artery**, a little shorter and smaller than the right, runs horizontally in front of the descending aorta and left bronchus to the root of the left lung, where it divides into two branches, one for each lobe of the lung. Above, it is connected to the concavity of the aortic arch by the ligamentum arteriosum, on the left of which is the left recurrent laryngeal nerve, and on the right the superficial part of the cardiac plexus. The ligament of the left vena cava (p. 704) passes from its lower border to the upper left pulmonary vein.

The branches of the pulmonary arteries to the bronchopulmonary segments are described with the anatomy of the lungs (pp. 1341, 1342).*

Applied Anatomy.—Embolism of the pulmonary trunk by a clot of blood coming from the right side of the heart in patients with heart-disease, or from a thrombosed deep vein after operations, is a common cause of sudden or rapid death.

The treatment of congenital stenosis of the pulmonary trunk, both with and without an associated "right to left intracardiac shunt" has advanced rapidly in recent years. From the indirect "systemic/pulmonary vessel anastomosis"† to the direct blind approach to the narrow pulmonary orifice and right ventricular outflow tract, and finally *via* the open dry heart techniques employing hypothermia or suitable pump/oxygenator circulatory replacement machines.‡

THE AORTA

The **aorta** is the main trunk of the series of vessels which convey the oxygenated blood to the tissues of the body. It begins at the upper part of the left ventricle, where it is about 3 cm. in diameter, and after ascending for a short distance, arches backwards and to the left, over the root of the left lung; it then descends within the thorax on the left side of the vertebral column, gradually inclining towards the median plane, and enters the abdominal cavity through the aortic hiatus in the diaphragm. Considerably diminished in size (about 1.75 cm. in diameter), it ends a little to the left of the median plane, at the level of the lower border of the fourth lumbar vertebra, by dividing into the right and left common iliac arteries. For convenience it is described in several portions, viz. the *ascending aorta*, the *arch of the aorta*, and the *descending aorta*, the last being divided into the *thoracic* and *abdominal aortae*.

THE ASCENDING AORTA

The **ascending aorta** (figs. 656, 677 and 1099) is about 5 cm. long. It begins at the base of the left ventricle, on a level with the lower border of the third costal cartilage, behind the left half of the sternum; it passes obliquely upwards, forwards and to the right, behind the sternum, as high as the upper border of the second right costal cartilage, describing a slight curve in its course. At its origin, opposite the cusps of the aortic valve, there are three small dilatations called the *aortic sinuses*. At the union of the ascending aorta with the aortic arch the calibre of the vessel is slightly increased, owing to a bulging of its right wall. This dilatation is termed the *bulb of the aorta*, and, on transverse section at this level, the vessel presents a somewhat oval outline.

Relations.—The ascending aorta is contained within the fibrous pericardium, and is enclosed in a tube of the serous pericardium, common to it and the pulmonary trunk (figs. 655 and 1099). *Anteriorly*, its lower part is related to the infundibulum of the right ventricle (p. 710), the commencement of the pulmonary trunk and the auricle of the right atrium; higher up, it is separated from the sternum by the pericardium, the right pleura, the anterior margin of the right lung, some loose areolar tissue and the remains of the thymus; *posteriorly*, it is related successively to the left atrium, the right pulmonary artery and the right bronchus; on its *right side*, to the superior vena cava and right atrium, the former lying partly behind it; on its *left side*, first to the left atrium and, at a higher level, to the pulmonary trunk.

Branches.—The branches of the ascending aorta are the right and left coronary arteries (figs. 659, 678), which supply the heart; they arise from the aortic sinuses immediately above the attached margins of the valves of the aortic valve.

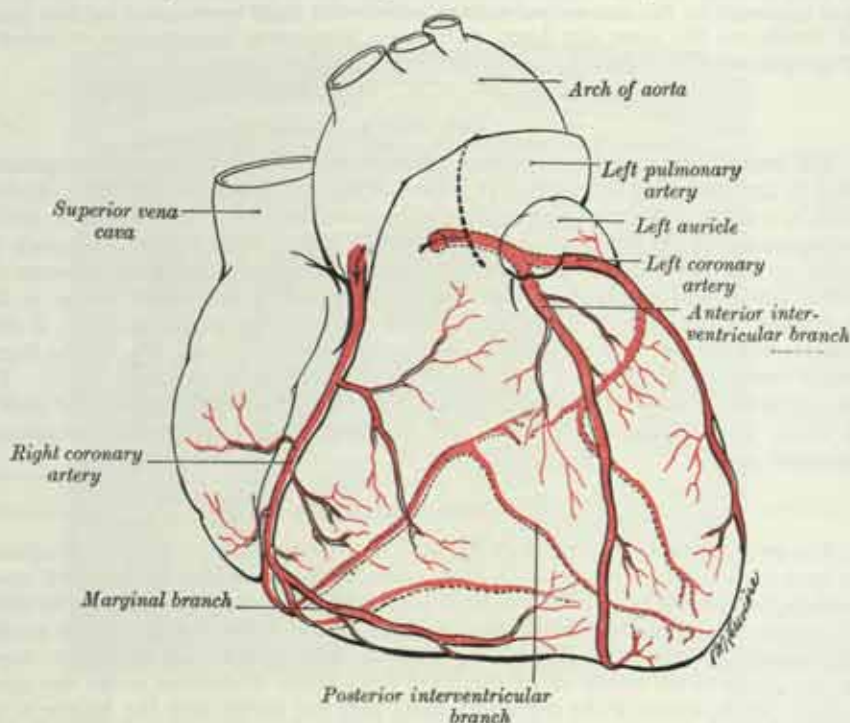
* For a detailed account, consult a paper by A. B. Appleton, *Lancet*, vol. ii, 1944, p. 592.

† Alfred Blalock, "Churchill Lecture", *Annals of Surgery*, vol. 125, No. 2, p. 129.

‡ R. C. Brock, *Brompton Hosp. Reports*, 18, 8, 1949.

The **right coronary artery** arises from the anterior aortic sinus. It passes at first forwards and to the right to emerge between the root of the pulmonary trunk and the right auricle and then runs downwards and to the right in the right portion of the coronary sulcus (atrioventricular groove), to the junction of the right and inferior margins of the heart. Here it turns to the left and runs on the back of the heart, as far as the posterior interventricular groove, where it anastomoses with the left coronary artery. The right coronary artery supplies branches to the right atrium and, by means of a *marginal branch* (fig. 678), to both surfaces of the right ventricle. Near its termination it gives off a *posterior interventricular branch*, which runs forwards in the posterior interventricular groove, supplies branches to both ventricles and anastomoses near the apex of the heart with the anterior interventricular branch of the left coronary artery.

FIG. 678—A scheme showing the course of the coronary arteries.



The **left coronary artery**, larger than the right, arises from the left posterior aortic sinus and, after a short course forwards between the pulmonary trunk and the left auricle, turns to the left in the coronary sulcus. It then passes backwards round the left margin of the heart and accompanies the coronary sinus as far as the interventricular groove, where it anastomoses with the right coronary artery. It supplies branches to the left atrium and the base of the left ventricle. At the point where it turns to the left, the left coronary artery gives off a large *interventricular branch*, which descends in the anterior interventricular groove, to the incisura apicis cordis. This branch supplies both ventricles and anastomoses with the interventricular branch of the right coronary artery. In many subjects it turns round the apex of the heart and runs backwards for a variable distance in the posterior interventricular groove (fig. 678).

There is a very free anastomosis between the minute branches and between the capillaries of the two coronary arteries in the substance of the heart.*

Peculiarities.—Very rarely the coronary arteries arise by a common trunk; or their number may be increased to three or four. The areas of distribution of the two arteries on the diaphragmatic surface of the heart are subject to considerable variation.

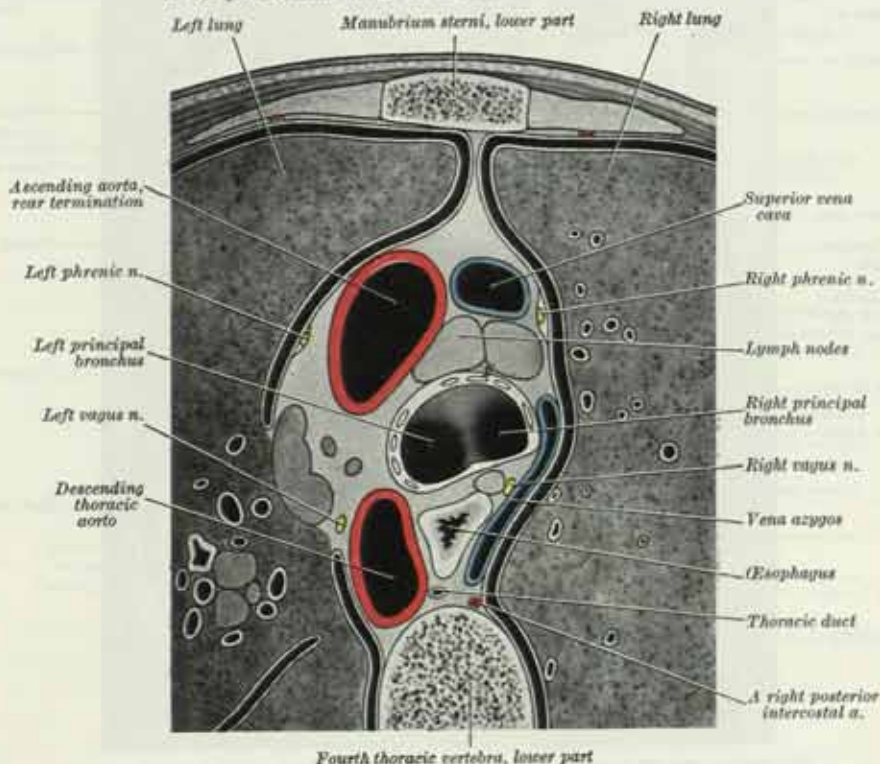
* Consult in this connexion *The Blood Supply of the Heart*, by Louis Gross, 1921.

Applied Anatomy.—The sudden blocking of a coronary artery by an embolus, or its more gradual obstruction by arterial disease or thrombosis, is a common cause of sudden death in persons past middle age. If the obstruction to the passage of blood is incomplete, the patient may suffer from *angina pectoris*, a condition associated with agonising pain in the precordial region and down the left arm.

THE ARCH OF THE AORTA

The **arch of the aorta** (figs. 680, 681) connects the ascending with the descending aorta; it begins behind the manubrium sterni at the level of the upper border of the second right sternocostal articulation, and runs at first upwards, backwards and to the left in front of the trachea; it is then directed backwards on the left side

FIG. 679.—A transverse section through the mediastinum at the level of the lower part of the body of the fourth thoracic vertebra.



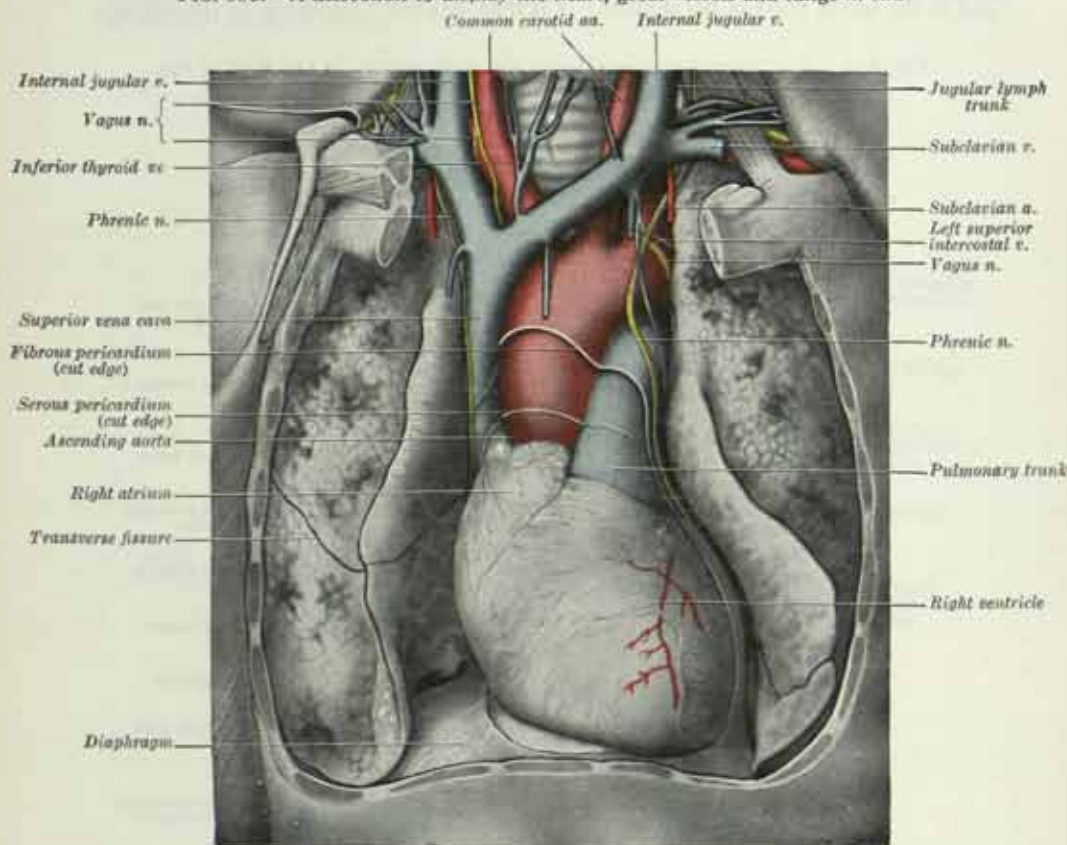
of the trachea, and finally passes downwards on the left side of the body of the fourth thoracic vertebra, at the lower border of which it is continuous with the descending aorta. Its termination corresponds to the sternal extremity of the second, left costal cartilage (fig. 668). It thus forms two curvatures: one with its convexity upwards, the other with its convexity forwards and to the left. Its upper border is usually about the level of the middle of the manubrium sterni.

Relations.—*Anteriorly and to the left* the vessel is covered with the left mediastinal pleura, under cover of which it is crossed by four nerves; in order from before backwards these are: the left phrenic, the lower of the cervical cardiac branches of the left vagus, the superior cervical cardiac branch of the left sympathetic, and the trunk of the left vagus. As the left vagus crosses the arch it gives off its recurrent laryngeal branch, which hooks round below the vessel to the left of the ligamentum arteriosum and then passes upwards on its right side. The left superior intercostal vein runs obliquely upwards and forwards on this surface of the arch, crossing superficial to the vagus but deep to the phrenic nerve (fig. 680). The left lung and pleura separate all these structures from the chest wall. *Posteriorly and to the right*, the trachea and the deep cardiac plexus, the left recurrent laryngeal nerve, the œsophagus, the thoracic duct and the vertebral column are successively in relation

to the vessel. *Above*, the brachiocephalic (innominate), left common carotid and left subclavian arteries arise from the convexity of the arch and are crossed close to their origins by the left brachiocephalic (innominate) vein. *Below*, the arch is related to the bifurcation of the pulmonary trunk, the left principal bronchus, the ligamentum arteriosum (p. 169), the superficial part of the cardiac plexus and the left recurrent laryngeal nerve.

In the foetus the lumen of the aorta is considerably narrowed between the origin of the left subclavian artery and the attachment of the ductus arteriosus, forming what is termed the *aortic isthmus*, while immediately beyond the ductus arteriosus

FIG. 68o.—A dissection to display the heart, great vessels and lungs *in situ*.



The sternum and the sternal ends of the costal cartilages, together with the parietal pleura on each side, have been excised, and the mediastinal pleura and parietal layer of the pericardium over the antero-superior surface of the heart have been removed. Both lungs have been retracted to expose the heart fully, and the epicardium has been dissected off the heart and the roots of the great vessels.

On the right side, the inferior cardiac branch of the vagus nerve descends between the brachiocephalic (innominate) artery and the right brachiocephalic (innominate) vein. On the left side, a communication descends from the left superior intercostal vein and crosses the aortic arch and the left pulmonary artery to become continuous with the oblique vein of the left atrium.

the vessel presents a fusiform dilatation which His named the *aortic spindle*—the point of junction of the two parts being marked in the concavity of the arch by an indentation or angle. These conditions persist, to some extent, in the adult, where His found that the average diameter of the spindle exceeded that of the isthmus by 3 mm.

Peculiarities.—The summit of the arch of the aorta is usually about 2.5 cm. below the upper border of the sternum; but it may be considerably higher or lower than this. Sometimes the aorta arches over the root of the right lung (right aortic arch) instead of over that of the left, and passes down on the right side of the vertebral column, a condition which is normal in birds. In such cases there is usually a transposition of the thoracic and of the abdominal viscera. Less frequently the aorta, after arching over the root of the right lung, passes behind the oesophagus to gain its usual position on the left side of the vertebral column; this peculiarity is not accompanied by transposition of the viscera. The aorta occasionally divides, as in some quadrupeds, into an ascending

and a descending trunk, the former of which is directed vertically upwards, and subdivides into three branches, to supply the head and upper limbs. Sometimes the aorta subdivides near its origin into two branches, which soon reunite; in these cases the œsophagus and trachea usually pass through the interval between the two branches; this is the normal condition of the vessel in the reptilia and is due to persistence of a part of the right dorsal aorta which usually disappears (fig. 170).

Radiological appearance.—The shadow cast by the terminal part of the arch is easily seen in antero-posterior radiographs (Pl. XIX) and is sometimes called the 'aortic knuckle'. The arch may also be seen in left anterior oblique radiographs enclosing a translucent space, 'the aortic window', in which may be seen the shadows of the pulmonary trunk and its left branch.

Branches (figs. 680, 683).—Three branches are given off from the upper aspect of the arch of the aorta, viz.: the brachiocephalic trunk (innominate), the left common carotid and the left subclavian.

FIG. 681.—A transverse section through the mediastinum at the level of the upper part of the body of the fourth thoracic vertebra.



Note that the arch of the aorta passes backwards, with only a slight inclination towards the left side.

Peculiarities.—The branches may spring from the commencement of the arch or upper part of the ascending aorta; or the distance between them at their origins may be increased or diminished, the most frequent change in this respect being the approximation of the left carotid artery to the brachiocephalic trunk artery.

The number of the primary branches may be reduced to one; more commonly there are two, the left carotid arising from the brachiocephalic trunk, or (more rarely) the carotid and subclavian arteries of the left side arising from a left brachiocephalic trunk. But the number may be increased to four, through the right carotid and subclavian arteries arising directly from the aorta; in most of these cases the right subclavian arises from the left end of the arch and passes to the right behind the œsophagus (see also p. 170). Another common variation in which there are four primary branches is that where the left vertebral artery arises from the arch of the aorta between the left carotid and subclavian arteries. Lastly, the number of trunks may be increased to five or six; very rarely, the external and internal carotid arteries arise separately, the common carotid being absent on one or both sides. In some few cases six branches have been found, and this condition is associated with the origin of both vertebral arteries from the arch.

When the aorta arches over to the right side, the arrangement of the three branches is reversed: there is a left brachiocephalic trunk, and the right carotid and right subclavian arteries arise separately. In other cases, where the aorta takes its usual course,

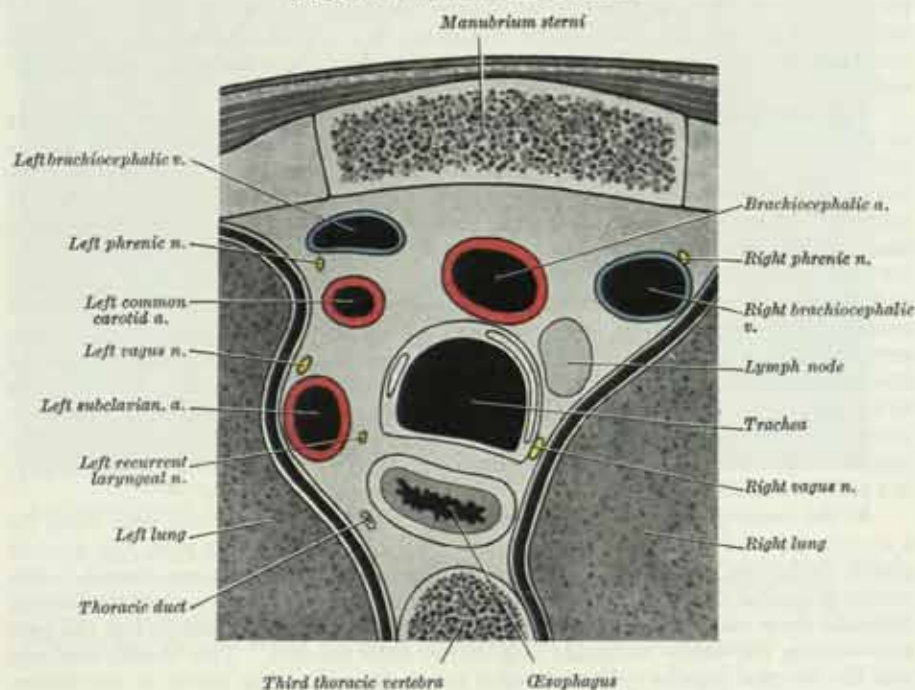
right brachiocephalic (innominate) vein, the upper part of the superior vena cava, and the pleura; and on the *left side*, the remains of the thymus, the origin of the left common carotid artery, the inferior thyroid veins, and at a higher level the trachea.

Branches.—The brachiocephalic artery is usually devoid of branches other than its terminal ones, but occasionally the *thyroidea ima* arises from it, and sometimes it gives off a *thymic* or a *bronchial branch*.

The **thyroidea ima**, small and inconstant, ascends in front of the trachea to the isthmus of the thyroid gland, in which it ends. It occasionally arises from the aorta, or from the right common carotid, subclavian or internal thoracic arteries.

Peculiarities.—The brachiocephalic artery sometimes projects above the upper border of the manubrium sterni. It may divide above the level of the sternoclavicular

FIG. 683.—A transverse section through the superior mediastinum at the level of the body of the third thoracic vertebra.



joint, less frequently below it. When the aortic arch is on the right side, the brachiocephalic artery is directed to the left side of the neck.

THE ARTERIES OF THE HEAD AND NECK

The principal arteries of the head and neck are the two common carotids; they ascend in the neck till they reach the level of the upper border of the thyroid cartilage, where each divides into two branches, viz. (1) the external carotid, supplying the exterior of the head, the face and the greater part of the neck; (2) the internal carotid, supplying the parts within the cranial and orbital cavities.

The common and internal carotid arteries, together with the veins and nerves which accompany them, are situated in a cleft on each side of the neck. This cleft may be said to possess three walls; a posterior, formed mainly by the cervical vertebræ with their attached muscles; a medial, consisting of the trachea, œsophagus, thyroid gland, larynx and the constrictor muscles of the pharynx; and an anterolateral, made up of the Sternomastoid with, at different levels, the Omohyoid, Sternohyoid, Sternothyroid, and the Digastric and Stylohyoid muscles.

THE COMMON CAROTID ARTERIES

The **common carotid arteries** differ in length and in their mode of origin. The *right* artery begins at the bifurcation of the brachiocephalic trunk behind the right sternoclavicular joint and is confined to the neck. The *left* artery springs from the highest part of the arch of the aorta immediately behind and to the left of the brachiocephalic trunk, and therefore consists of a thoracic and a cervical portion.

The **thoracic portion of the left common carotid artery** (figs. 682, 683) ascends from the arch of the aorta to the level of the left sternoclavicular joint, where it is continuous with the cervical portion. It lies at first in front of the trachea, but later inclines to its left side.

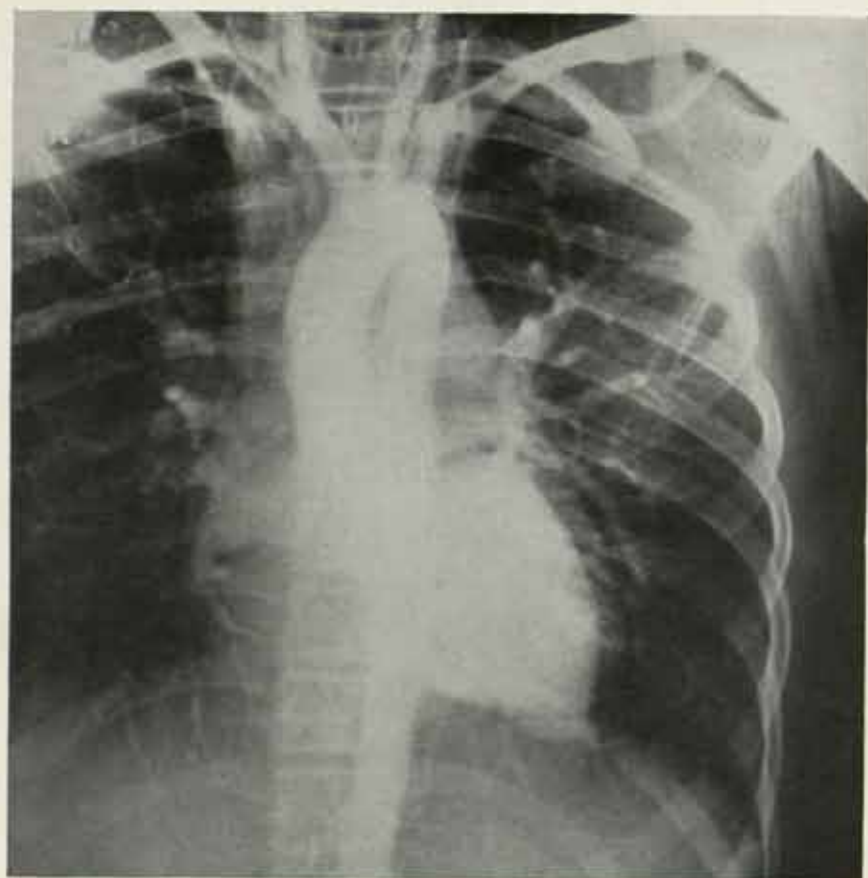
Relations.—*In front*, it is separated from the manubrium sterni by the Sternohyoid and Sternothyroid muscles, the anterior portions of the left pleura and lung, the left brachiocephalic vein and the remains of the thymus; *behind*, it is related first to the trachea, then to the left subclavian artery, the left edge of the œsophagus, the left recurrent laryngeal nerve and the thoracic duct. On its *right side* it is related below to the brachiocephalic trunk, and above to the trachea, the inferior thyroid veins and the remains of the thymus; at its *left side* are the left vagus and phrenic nerves, the left pleura and lung.

The **cervical portions** of the common carotid arteries resemble each other so closely that one description will apply to both (figs. 682, 686). Each passes obliquely upwards, from behind the sternoclavicular joint, to the level of the upper border of the thyroid cartilage, where it divides into the external and internal carotid arteries. At its point of division the vessel shows a dilatation, termed the *carotid sinus*, which usually involves, and may be restricted to, the proximal part of the internal carotid artery. In this situation the tunica media is thinner than elsewhere and the tunica adventitia, which is relatively thick, contains a large number of sensory nerve-endings, derived from the glosso-pharyngeal nerve (p. 1128). The structure of the walls of the sinus enables it to react readily to changes in the arterial blood-pressure and to bring about appropriate modifications reflexly. Owing to its situation on the main artery of supply to the brain its function as a 'pressor-receptor' mechanism enables it to exercise control over intracranial pressure. The *carotid body*, which lies behind the point of division of the common carotid artery, is a small, reddish-brown structure; it acts as a 'chemo-receptor'.*

At the lower part of the neck the two arteries are separated from each other by a narrow interval which contains the trachea; but at the upper part, the thyroid gland, the larynx, and the pharynx project forwards between the two vessels. The common carotid artery is contained in the carotid sheath (p. 566), which is derived from the deep cervical fascia, and is composed of loose cellular tissue, but the part surrounding the artery is thicker and denser than the rest. This sheath encloses also the internal jugular vein and vagus nerve, the vein lying lateral to the artery, and the nerve between the artery and vein, on a plane posterior to both. The superior ramus of the ansa cervicalis (r. descendens n. hypoglossi) is embedded in its anterior wall (fig. 564).

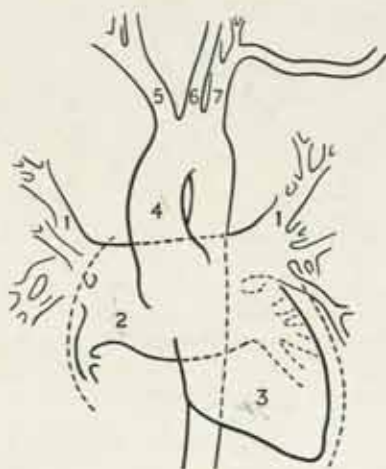
Relations.—The common carotid artery is crossed *anterolaterally*, at the level of the cricoid cartilage, by the superior belly of the Omohyoid. Below the level of this muscle the artery is very deeply seated, being covered with the skin, superficial fascia, Platysma, deep cervical fascia, Sternomastoid, Sternohyoid and Sternothyroid. Above the level of the Omohyoid it is more superficial, being covered merely by the skin, the superficial fascia, Platysma, deep cervical fascia and the medial margin of the Sternomastoid; this part of the artery is crossed obliquely, thyroid artery. In front of, or embedded in, its sheath is the superior ramus of the ansa cervicalis (r. descendens n. hypoglossi), this branch being joined by the inferior ramus of the ansa, which springs from the second and third cervical nerves and crosses the vessel obliquely. The superior thyroid vein usually crosses the artery near its termination, and the middle thyroid vein a little below the level of the cricoid cartilage; the anterior jugular vein crosses the artery just above the clavicle, but is separated from it by the Sternohyoid and Sternothyroid muscles. *Behind*, the artery is separated from the transverse processes of the fourth, fifth and sixth cervical vertebrae by the Longus cervicis and Longus capitis muscles and the origin of the

* Schumacher (*Zeitschr. f. mikroskop.-anat. Forsch.*, 43, 1938).



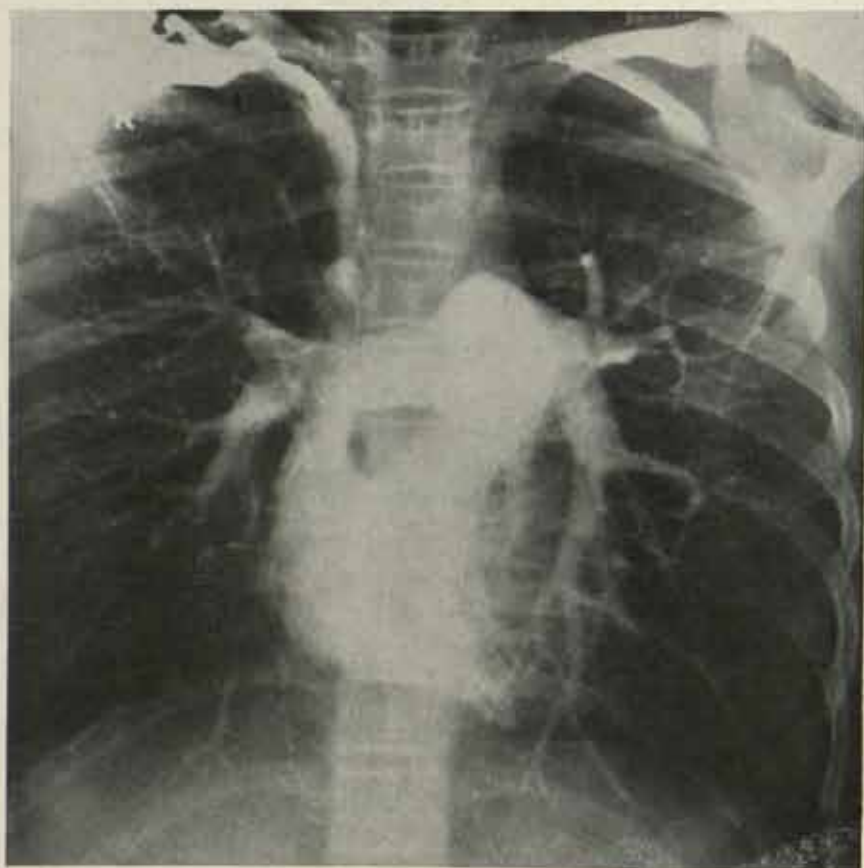
Angiocardiogram, (Dr. Frances Gardner), showing the left side of the heart in a child of 11 years ; antero-posterior view.

1. Upper pulmonary vein. 2. Left atrium. Note that owing to the great obliquity of the atrial septum, the left atrium extends to the right behind the right atrium. 3. Left ventricle. 4. Ascending aorta. 5. Brachio-cephalic trunk. 6. Left common carotid artery. 7. Left subclavian artery. Note that the arms of the patient are raised above the head and that, as a result, the distal end of the artery passes upwards.



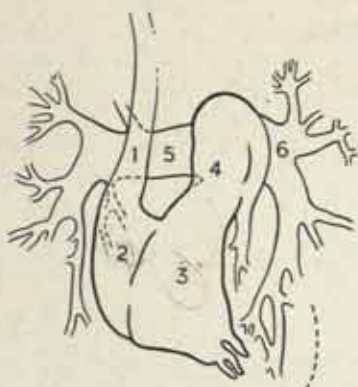
Key to Plate XXa.

PLATE XXb.



Angiocardiogram, (Dr. Frances Gardner), showing the right side of the heart in a child of 12 years; antero-posterior view.

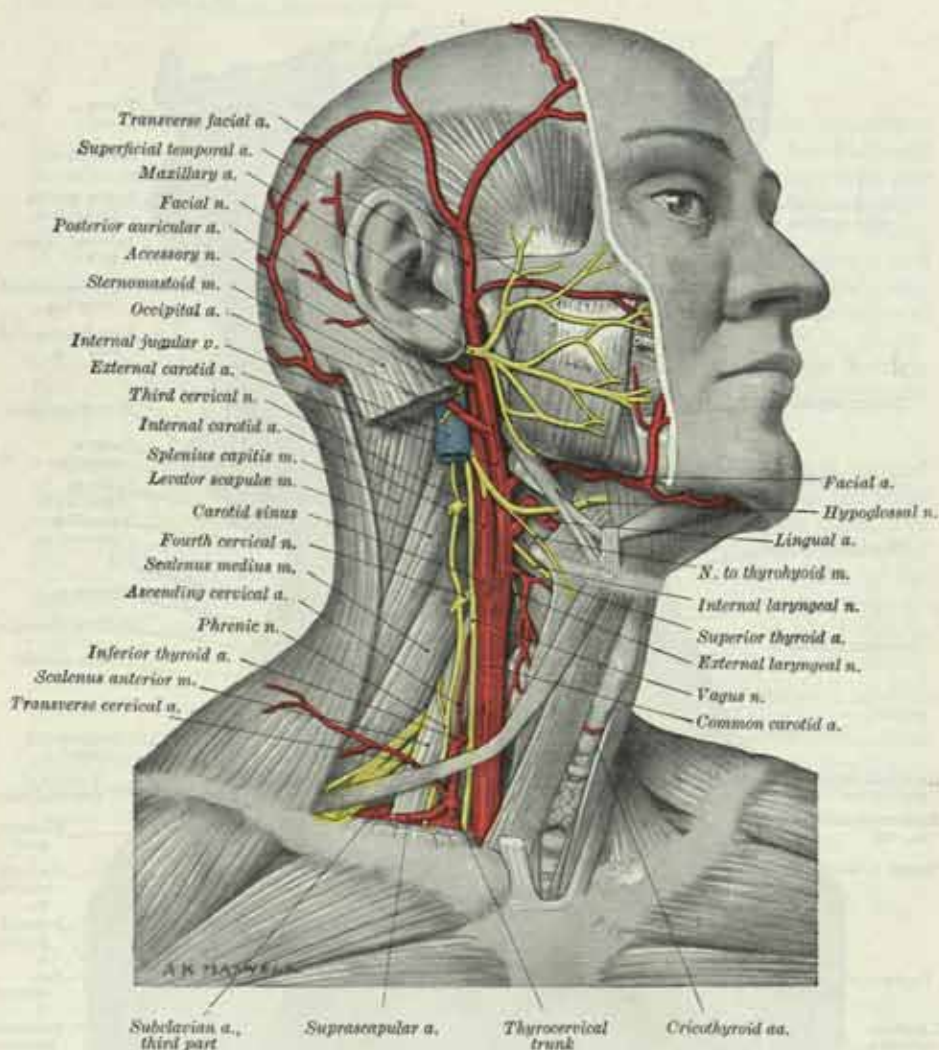
1. Superior vena cava. 2. Right atrium. 3. Right ventricle. 4. Pulmonary trunk.
5. Right pulmonary artery. 6. Left pulmonary artery.



Key to Plate XXb.

Scalenus anterior, the sympathetic trunk and the ascending cervical artery being interposed between the artery and the muscles. Below the level of the sixth cervical vertebra the common carotid artery lies in the angle between the Scalenus anterior and the Longus cervicis (fig. 685), anterior to the vertebral vessels, the inferior thyroid and subclavian arteries, the sympathetic trunk, and, on the left side, the thoracic duct. *Medial* to it are the œsophagus, trachea, the inferior thyroid artery

FIG. 684.—A dissection of the right side of the neck, showing the carotid and subclavian arteries and their branches.



The parotid and submandibular glands have been removed together with the lower part of the internal jugular vein, most of the sternomastoid muscle, and the upper parts of the stylohyoid and posterior belly of the digastric muscle.

and recurrent laryngeal nerve; at a higher level, the larynx and pharynx are medial to the artery; the lobe of the thyroid gland overlaps it anteromedially. *Lateral* to the artery is the internal jugular vein; *posterolaterally*, in the angle between it and the internal jugular vein is the vagus nerve.

On the right side, at the lower part of the neck, the recurrent laryngeal nerve crosses obliquely behind the artery; the right internal jugular vein diverges from the artery, but the left vein approaches and often overlaps the lower part of the vessel.

inferior thyroid arteries. The branches to the gland are: The anterior branch which follows the medial border of the upper pole of the lobe and supplies principally the anterior surface, sending a branch across the upper border of the isthmus to anastomose with the artery of the opposite side. The posterior branch descends on the posterior border of the gland, supplying its medial and lateral surfaces, and anastomoses with the inferior thyroid artery. Sometimes a lateral branch is distributed to the lateral surface of the gland.

Besides the arteries distributed to the muscles and to the thyroid gland, the superior thyroid artery supplies the following named branches:

Infrahyoid.
Sternomastoid.

Superior laryngeal.
Cricothyroid.

The **infrahyoid artery** is small and runs along the lower border of the hyoid bone deep to the Thyrohyoid, and anastomoses with the vessel of the opposite side.

The **sternomastoid branch** frequently arises from the external carotid artery; it runs downwards and laterally across the sheath of the common carotid artery.

The **superior laryngeal artery**, is frequently a separate branch of the external carotid artery; it accompanies the internal laryngeal nerve and passes deep to the Thyrohyoid; it pierces the lower part of the thyrohyoid membrane, and supplies the larynx, anastomosing with the artery of the opposite side, and with the inferior laryngeal artery, a branch of the inferior thyroid artery.

The **cricothyroid branch** is small and runs transversely across the upper part of the conus elasticus communicating with the artery of the opposite side.

2. The **ascending pharyngeal artery** (fig. 694), the smallest branch of the external carotid artery, is a long, slender vessel. It arises close to the origin of the external carotid artery, and ascends vertically between the internal carotid artery and the side of the pharynx to the under surface of the base of the skull, being crossed by the Styloglossus and the Stylopharyngeus and lying on the Longus capitis; it anastomoses freely with the ascending palatine branch of the facial artery.

Its branches are:

Pharyngeal.

Inferior tympanic.

Meningeal.

The **pharyngeal branches**, three or four in number, supply the Constrictor muscles and the Stylopharyngeus. A branch of variable size is distributed to the palate, and may take the place of the ascending palatine branch of the facial artery; it runs downwards and forwards between the superior border of the Superior constrictor and the Levator veli palatini, and accompanies the latter muscle to the soft palate; it gives some minute branches to the tonsil, and supplies a twig to the auditory tube.

The **inferior tympanic artery** is a small branch which passes through the temporal bone, in the canaliculus for the tympanic branch of the glossopharyngeal nerve, to supply the medial wall of the tympanic cavity.

The **meningeal branches** are several small vessels which supply the dura mater. One enters the cranium through the foramen lacerum; a second passes through the jugular foramen; and, occasionally, a third passes through the hypoglossal (anterior condylar) canal.

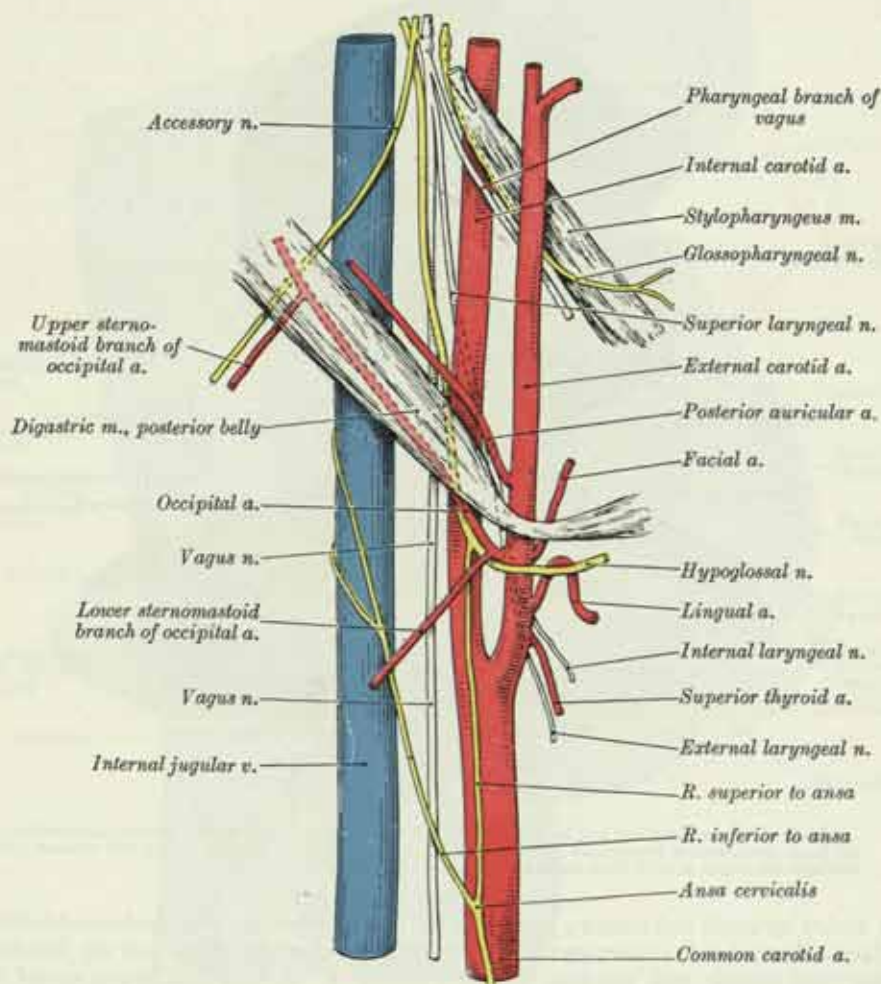
Numerous small vessels supply the Longi capitis et cervicis, the sympathetic trunk, the hypoglossal and vagus nerves, and the lymph glands; they anastomose with branches of the ascending cervical and vertebral arteries.

3. The **lingual artery** (fig. 684) arises from the anteromedial surface of the external carotid artery opposite to the tip of the greater cornu of the hyoid bone, and between the superior thyroid and facial arteries; it ends in the tongue. Running obliquely upwards and medially at first, it then curves downwards and forwards to the greater cornu of the hyoid bone, forming a loop which is characteristic of the vessel; it passes deep to the posterior border of the Hyoglossus, runs horizontally forwards under cover of that muscle, and finally, ascending almost perpendicularly, courses tortuously forwards on the under surface of the tongue as far as the tip (fig. 688).

Course and relations.—The *first part* of the lingual artery lies in the carotid triangle; superficial to it are the skin, fascia and Platysma; deep to it, the Middle constrictor muscle. It runs upwards and medially for a short distance, and then descends to the level of the hyoid bone, forming a loop, which is crossed by the hypoglossal nerve. The *second part* of the artery courses along the upper border of the

hyoid bone, deep to the Hyoglossus, the tendon of the Digastric or its fascial retinaculum, the Stylohyoid, the lower part of the submandibular gland and the posterior part of the Mylohyoid; the Hyoglossus separates the artery from the hypoglossal nerve and its vena comitans; in this part of its course it lies on the Middle constrictor muscle and crosses the stylohyoid ligament. It is accompanied by the lingual veins (p. 842). The *third part* of the artery is named the *arteria profunda linguae*. It bends sharply upwards near the anterior border of the Hyoglossus, and then runs forwards on the inferior surface of the tongue near the frenulum, accompanied by the lingual nerve. Medially, it is related to the Genioglossus; laterally, to the Longitudinalis

FIG. 686.—A diagram showing the structures crossing the internal jugular vein and carotid arteries, and those intervening between the external and internal carotid arteries. Modified from a figure in R. B. Green's *Human Anatomy for Dental Students*, 1923.



linguae inferior; below, to the mucous membrane of the tongue. At the tip of the tongue it anastomoses with the lingual artery of the opposite side.

The lingual artery is the principal vessel of supply to the tongue and the structures in the floor of the mouth. Its branches are as follows:

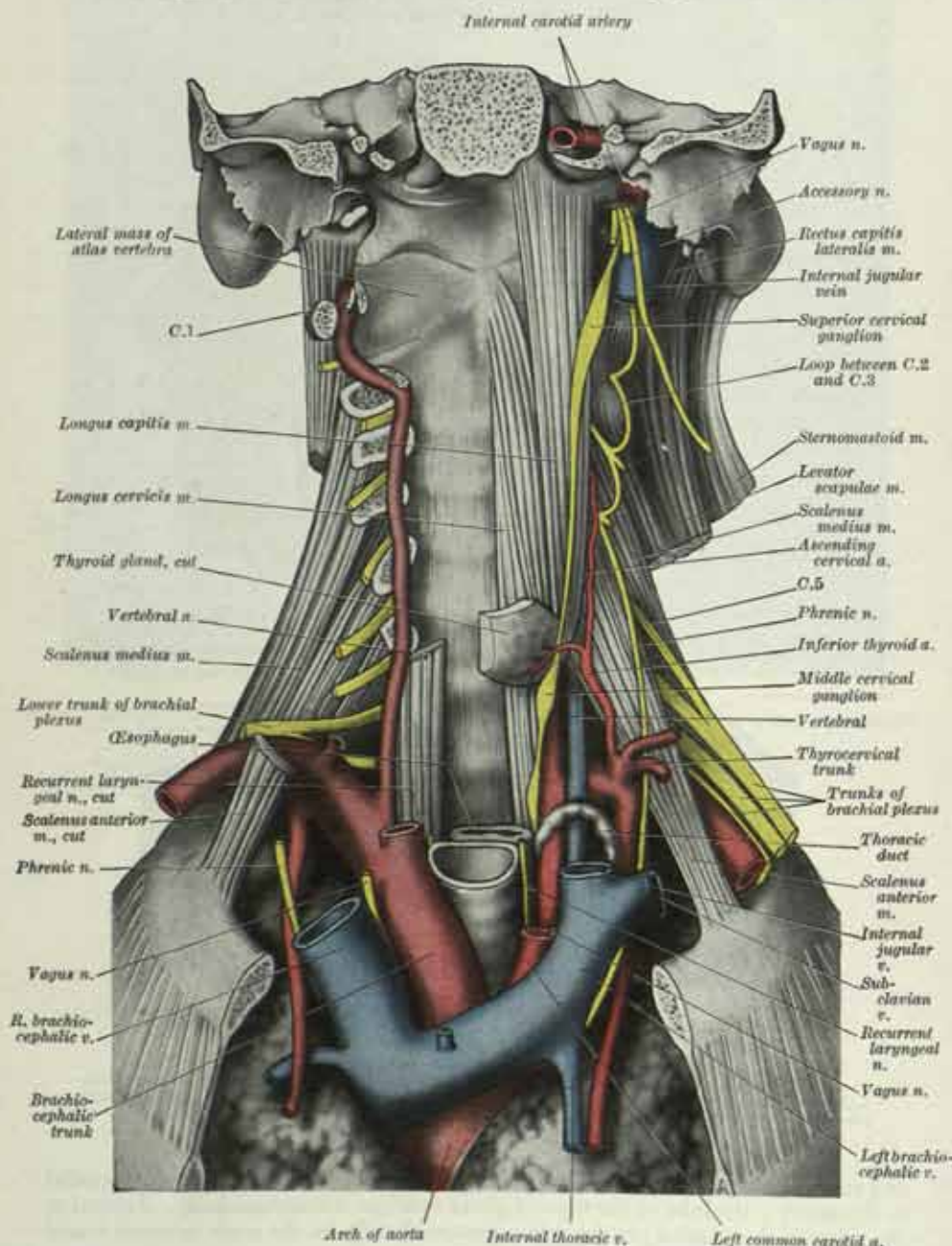
The **suprahyoid branch** is very small; it runs along the upper border of the hyoid bone, and anastomoses with its fellow of the opposite side.

The **rami dorsales linguae** consist usually of two or three small branches; they arise under cover of the Hyoglossus, ascend to the posterior part of the dorsum of the tongue, and supply the mucous membrane of the tongue, the palatoglossal arch, the tonsil, soft palate and epiglottis; they anastomose with the vessels of the opposite side.

The **sublingual artery** arises at the anterior margin of the Hyoglossus, and runs forward between the Genioglossus and Mylohyoid to the sublingual gland. It supplies

Peculiarities.—In about 12 per cent. of subjects the *right* common carotid artery arises above the level of the upper border of the sternoclavicular joint. It may arise as a separate branch from the arch of the aorta, or in conjunction with the left carotid.

FIG. 685.—A dissection to show the prevertebral region and the superior mediastinum. In addition, on the right side the costal elements of the upper six cervical vertebrae have been removed to expose the cervical part of the course of the vertebral artery. On the left side, the dissection shows most of the deep relations of the common carotid artery and the internal jugular vein.



The *left* common carotid artery varies in its origin more frequently than the *right*. In the majority of abnormal cases it arises in common with the brachiocephalic artery; if that artery be absent, the two carotids arise usually by a single trunk. It is rarely joined with the left subclavian, except in cases of transposition of the aortic arch.

Division of the common carotid artery may occur, higher than usual, at or about the level of the hyoid bone; more rarely it occurs below the usual level, opposite the middle of the larynx, or the lower border of the cricoid cartilage; one case was described by Morgagni, where the artery was only 4 cm. in length and divided at the root of the neck. Very rarely the artery ascends in the neck without undergoing division, either the external or the internal carotid being wanting. In a few cases the artery has been found absent, the external and internal carotid arteries arising directly from the arch of the aorta; this peculiarity existed on both sides in some instances, on one side only in others.

The common carotid artery usually supplies no branch; but it may give origin to the vertebral, the superior thyroid or its laryngeal branch, the ascending pharyngeal, the inferior thyroid, or the occipital.

THE EXTERNAL CAROTID ARTERY

The **external carotid artery** (figs. 684 and 693) begins opposite the upper border of the thyroid cartilage, at the level of the disc between the third and fourth cervical vertebræ, and, taking a slightly curved course, passes upwards and forwards, and then inclines backwards to a point behind the neck of the mandible midway between the tip of the mastoid process and the angle of the jaw, where, in the substance of the parotid gland, it divides into the superficial temporal and maxillary arteries. It diminishes rapidly in size, owing to the number and large size of its branches. In the child, it is a little smaller than the internal carotid artery; but in the adult, the two vessels are of nearly equal size. At its origin, where its pulsations are easily felt, it is contained within the carotid triangle (p. 752), and lies anterior to and nearer the median plane than the internal carotid artery; higher up it is situated lateral to this artery.

Relations.—Within the carotid triangle the external carotid artery is covered by the skin, the superficial fascia, the loop between the cervical branch of the facial nerve and the transverse (anterior cutaneous) nerve of the neck, the deep fascia, and the anterior margin of the Sternomastoid; it is crossed by the hypoglossal nerve and its vena comitans, by the lingual and (common) facial veins and sometimes by the superior thyroid vein. Leaving the carotid triangle it is crossed by the posterior belly of the Digastric and the Stylohyoid and then ascends between the latter muscle and the posteromedial surface of the parotid gland. Finally, it enters the gland, where it lies deep to the facial nerve and the junction of the superficial temporal and maxillary veins. Deeply, it is related at first to the wall of the pharynx, the superior laryngeal nerve, and the ascending pharyngeal artery. At a higher level the internal carotid artery is deep to it, but is separated from it by the styloid process, the Styloglossus and Stylopharyngeus muscles, the glossopharyngeal nerve, the pharyngeal branch of the vagus nerve and a part of the parotid gland (fig. 686).

THE BRANCHES OF THE EXTERNAL CAROTID ARTERY (figs. 684, 689)

The branches of the external carotid artery are:

- | | |
|--------------------------|--------------------------|
| 1. Superior thyroid. | 5. Occipital. |
| 2. Ascending pharyngeal. | 6. Posterior auricular. |
| 3. Lingual. | 7. Superficial temporal. |
| 4. Facial. | 8. Maxillary. |

1. The **superior thyroid artery** (fig. 684) arises from the front of the external carotid artery just below the level of the greater cornu of the hyoid bone and, divides into terminal branches at the apex of the lobe of the gland.

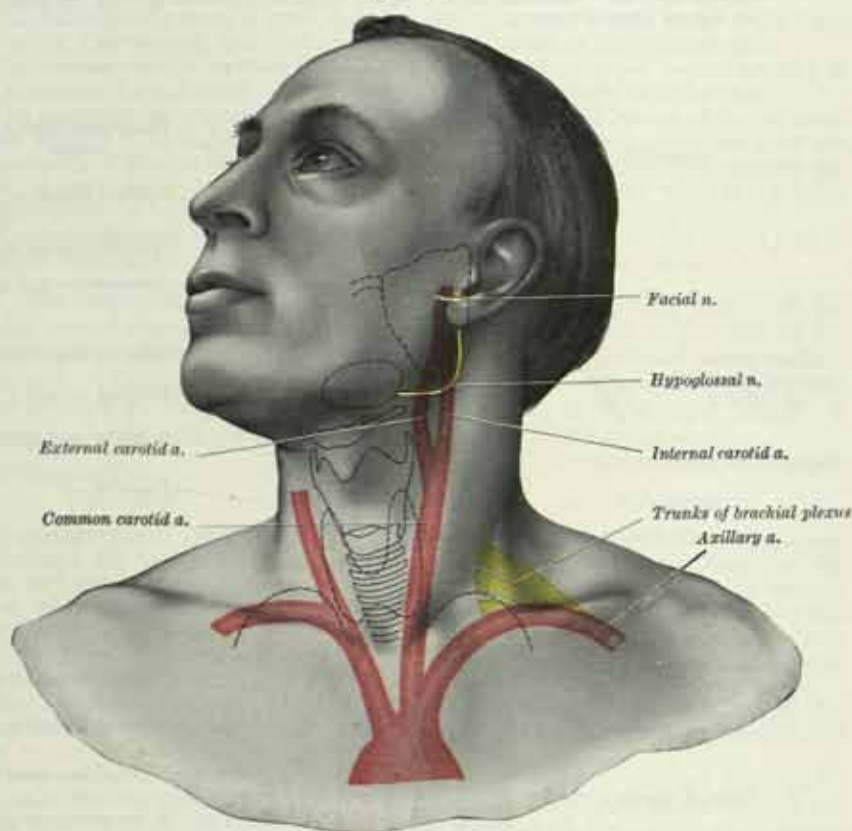
Relations.—From its origin beneath the anterior border of the Sternomastoid it runs downwards and forwards in the carotid triangle along the lateral border of the Thyrohyoid, and is covered by the skin, Platysma and fasciæ; it then passes under cover of the Omohyoid, Sternohyoid and Sternothyroid. To its medial side are the Constrictor pharyngis inferior and the external branch of the superior laryngeal nerve, but the nerve frequently lies on a more posterior plane.

Branches.—It distributes twigs to the adjacent muscles, and branches to the thyroid gland; it anastomoses with its fellow of the opposite side, and with the

the gland and gives branches to the Mylohyoid and neighbouring muscles, and to the mucous membrane of the mouth and gums. One branch runs behind the alveolar part of the mandible in the substance of the gum to anastomose with a similar artery from the other side; another pierces the Mylohyoid muscle and anastomoses with the submental branch of the facial artery.

4. The **facial artery** (figs. 689, 694) arises from the front of the external carotid artery in the carotid triangle a little higher than the lingual artery, and immediately above the greater cornu of the hyoid bone. Sheltered by the ramus of the mandible,

FIG. 687.—The surface relations of some of the important structures in the face and neck.



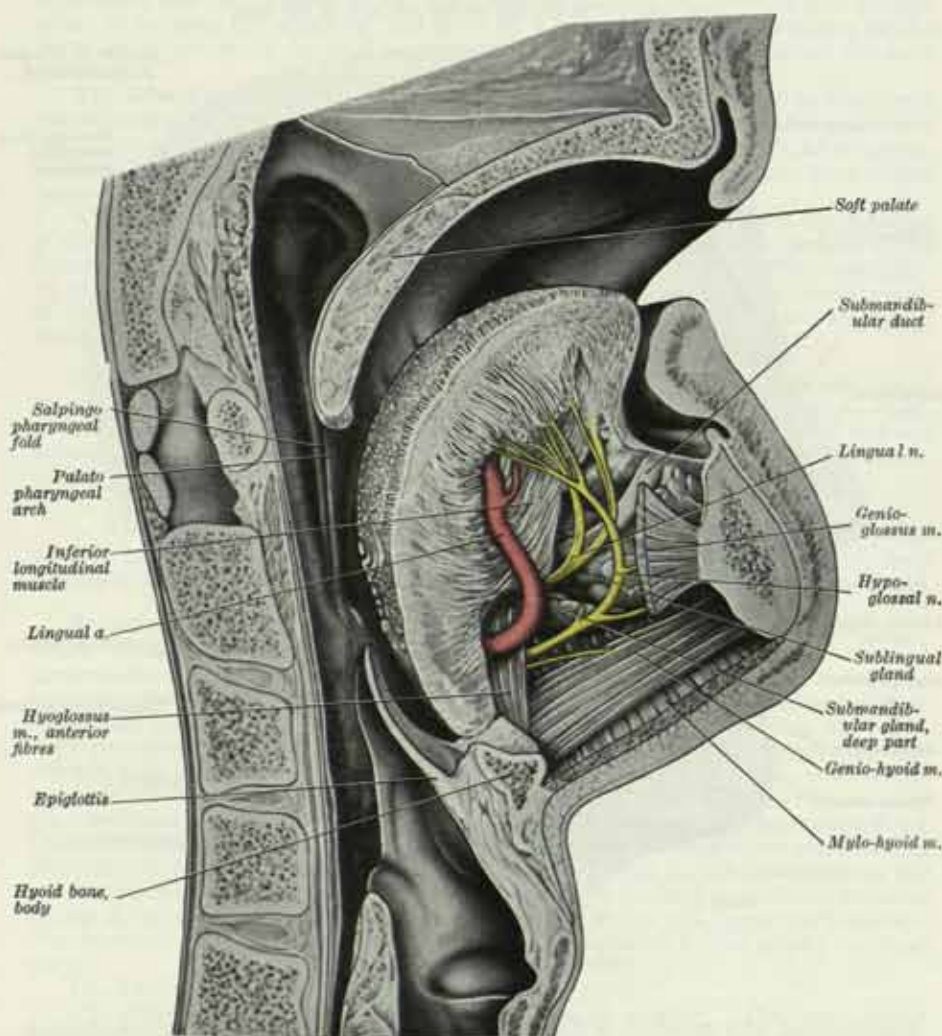
Note.—The parotid gland and its duct, the submandibular and thyroid glands and the apices of the lungs are shown as interrupted outlines. The hyoid bone and the thyroid, cricoid and tracheal cartilages are shown in solid black outlines.

it arches upwards and enters a groove on the posterior border of the submandibular gland. It next turns downwards and forwards between the gland and the Medial pterygoid muscle, and, reaching the lower border of the mandible, hooks round it at the anterior edge of the Masseter, and enters the face. On the face it passes forwards and upwards across the mandible and buccinator muscle almost to the angle of the mouth where its pulsations can be felt if the substance of the cheek be grasped lightly between the finger and thumb. It then ascends along the side of the nose, and ends at the medial palpebral commissure, where it supplies branches to the lacrimal sac, and anastomoses with the dorsal nasal branch of the ophthalmic artery. The facial artery is remarkably tortuous: in the neck to accommodate itself to the movements of the pharynx during deglutition, and on the face to accommodate itself to the movements of the mandible, lips and cheeks.

Relations.—*In the neck*, at its origin, the artery is superficial, being placed under cover of the skin, Platysma, and fasciæ, and often is crossed by the hypoglossal nerve.

It runs upwards and forwards, deep to the Digastric and Stylohyoid and to the posterior part of the submandibular gland. At first on the surface of the Middle constrictor of the pharynx, it may reach as high as the lateral surface of the Styloglossus, and it is then separated from the tonsil only by that muscle and the lingual fibres of origin of the Superior constrictor. Next, it descends to the lower border of the mandible, lying in a groove on the lateral aspect of the submandibular gland. *In*

FIG. 688.—A dissection of the left half of the tongue from the medial side, exposing the terminal portion of the second part and the first portion of the third part of the left lingual artery and the adjoining structures, in an edentulous subject.



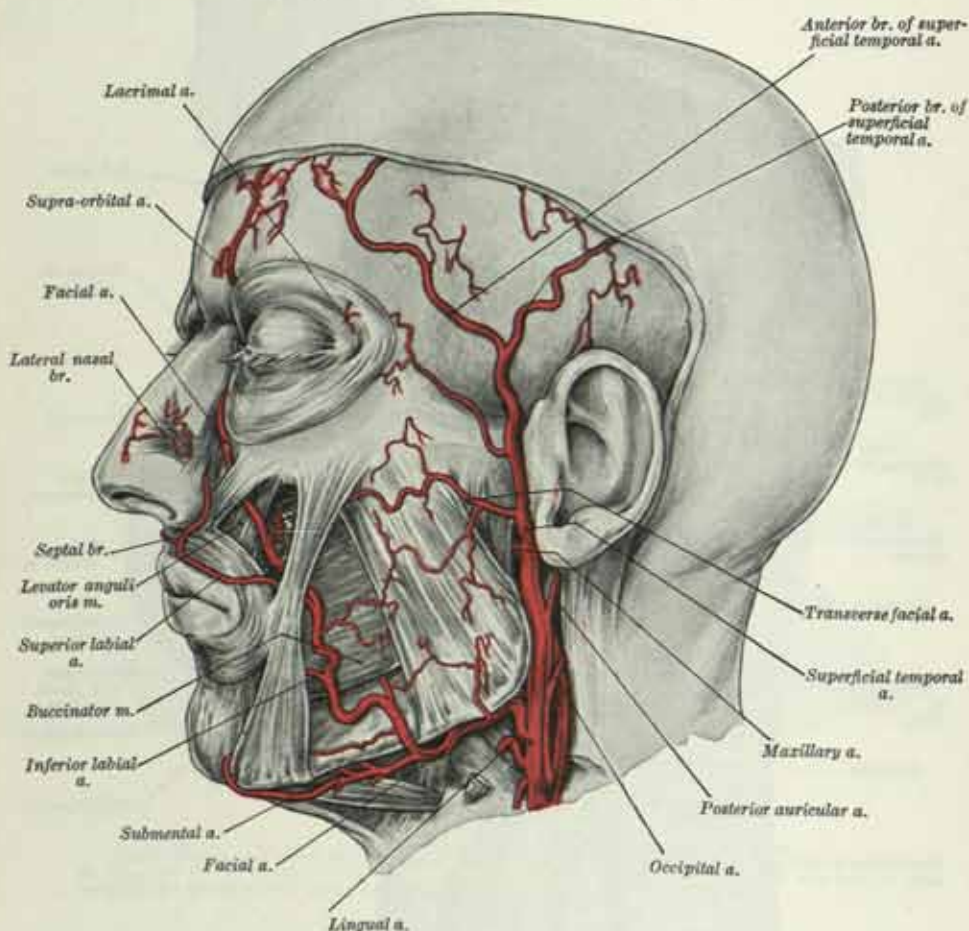
Note.—The section is slightly to the right side of the median plane, so that the right side of the nasal septum and the right lateral aspect of the dens (odontoid process) are exposed.

the face, where its pulsations can be felt as it passes over the base of the mandible, it is comparatively superficial, lying immediately beneath the Platysma. In its course over the face, it is under cover of the skin, the fat of the cheek, and, near the angle of the mouth, the Platysma, Risorius and Zygomaticus major. It rests on the Buccinator and Levator anguli oris, and passes either over or through the Levator labii superioris. Its terminal part is embedded in the fibres of the Levator labii superioris alaeque nasi. The anterior facial vein lies posterior to the artery, and, taking a more direct course across the face, is at some distance from the artery. At the anterior border of the Masseter the two vessels are in contact; in the neck the vein is superficial to the artery. The branches of the facial nerve cross the artery from behind forwards.

The facial artery supplies the muscles of facial expression and the tissues of the face, the submandibular gland, the tonsil and the soft palate. Its branches are given off in the neck (cervical) and in the face (facial).

Cervical branches.—The **ascending palatine artery** (fig. 694) arises close to the origin of the facial artery and passes up between the Styloglossus and Stylopharyngeus to the side of the pharynx, along which it ascends between the Superior constrictor and the Medial pterygoid muscles towards the base of the skull. Near the Levator veli palatini it divides into two branches: one follows the course of this muscle, and, winding over the upper border of the Superior constrictor, supplies the soft palate,

FIG. 689.—The arteries of the left side of the face.



anastomosing with its fellow of the opposite side and with the greater palatine branch of the maxillary artery; the other pierces the Superior constrictor and supplies the tonsil and the auditory tube, anastomosing with the tonsillar and ascending pharyngeal arteries.

The **tonsillar artery** is the *principal artery to the tonsil*. Sometimes derived from the ascending palatine artery, it ascends between the Medial pterygoid and Styloglossus, and at the upper border of the latter muscle, it perforates the Superior constrictor and ramifies in the tonsil and the root of the tongue.

The **glandular branches**, three or four large vessels, supply the submandibular salivary gland and lymph glands, the neighbouring muscles and the skin.

The **submental artery**, the largest cervical branch of the facial artery, springs from that artery just as it quits the submandibular gland: it runs forwards upon the Mylohyoid (fig. 689), below the body of the mandible. It supplies the surrounding muscles, and anastomoses with the sublingual branch of the lingual artery and with the mylohyoid branch of the inferior alveolar artery; at the chin it turns upwards over

the base of the mandible and divides into superficial and deep branches which anastomose with the inferior labial and mental arteries supplying the chin and lower lip.

Facial branches.—The **inferior labial artery** (fig. 689) arises near the angle of the mouth; it passes upwards and forwards under cover of the Depressor anguli oris and, penetrating the Orbicularis oris, runs in a tortuous course near the edge of the lower lip between this muscle and the mucous membrane. It supplies the glands, mucous membrane and muscles of the lower lip and anastomoses with the artery of the opposite side, and with the mental branch of the inferior alveolar artery.

The **superior labial artery** (fig. 689) is larger and more tortuous than the inferior. It follows a similar course near the edge of the upper lip, lying between the mucous membrane and the Orbicularis oris, and anastomoses with the artery of the opposite side. It supplies the upper lip, and gives off a *septal branch*, which ramifies on the lower and front part of the nasal septum, and an *alar branch*, which supplies the ala of the nose.

The **lateral nasal branch** (fig. 689) is derived from the facial artery as that vessel ascends along the side of the nose. It supplies the ala and dorsum of the nose, anastomosing with its fellow, with the septal and alar branches of the superior labial artery, with the dorsal nasal branch of the ophthalmic artery, and with the infra-orbital branch of the maxillary artery.

The anastomoses of the facial artery are very numerous, not only with the branches of the vessel of the opposite side, but, *in the neck*, with the sublingual branch of the lingual, with the ascending pharyngeal and with the palatine branch of the maxillary; *on the face*, with the mental branch of the inferior alveolar, the transverse facial branch of the superficial temporal, the infra-orbital branch of the maxillary and the dorsal nasal branch of the ophthalmic artery.

Peculiarities.—The facial artery not infrequently arises in common with the lingual artery constituting the *linguofacial trunk*. It varies in size, and in the extent to which it supplies the face; it occasionally ends by forming the submental artery, and not infrequently extends only as high as the angle of the mouth or nose. The deficiency is then compensated by enlargement of one of the neighbouring arteries.

5. The **occipital artery** (fig. 690) arises from the posterior aspect of the external carotid artery, opposite to the facial artery, and running at first on the deep surface of the posterior belly of the Digastric, ends in the posterior part of the scalp.

Relations.—Close to its origin, it is usually crossed by the hypoglossal nerve, which winds round it from behind forwards. The artery passes backwards and upwards deep to the lower border of the posterior belly of the Digastric, crossing in its course the internal carotid artery, the internal jugular vein, and the hypoglossal, vagus and accessory nerves (fig. 690). Reaching the interval between the transverse process of the atlas and the mastoid process of the temporal bone, it comes into contact with the lateral border of the Rectus capitis lateralis. It then runs in the occipital groove on the temporal bone, and here is covered by the mastoid process and the attachments to it of the Sternomastoid, Splenius capitis, Longissimus capitis and Digastric, and lies successively on the Rectus capitis lateralis, Obliquus superior and Semispinalis capitis. Finally, it turns upwards and pierces the fascia connecting the cranial attachment of the Trapezius with the Sternomastoid, and ascends in a tortuous course in the superficial fascia of the scalp, where it divides into numerous branches. The terminal portion of the occipital artery is accompanied by the greater occipital nerve.

The following branches arise from the occipital artery:

The **sternomastoid branches** are usually two in number. The *lower branch* generally arises from the beginning of the occipital artery, but sometimes springs directly from the external carotid artery. It passes downwards and backwards over the hypoglossal nerve and the internal jugular vein, and enters the substance of the Sternomastoid; it anastomoses with the sternomastoid branch of the superior thyroid artery. The *upper branch* arises from the occipital artery as it crosses the accessory nerve, and runs downwards and backwards superficial to the internal jugular vein. It enters the deep surface of the Sternomastoid in company with the accessory nerve.

The **mastoid branch**, small in size and sometimes absent, enters the cranial cavity through the mastoid foramen; it gives branches to the mastoid air-cells and the dura mater, and anastomoses with the middle meningeal artery.

The **auricular branch** supplies the back of the auricle and anastomoses with the posterior auricular artery.

Muscular branches are supplied to the Digastric, Stylohyoid, Splenius and Longissimus capitis.

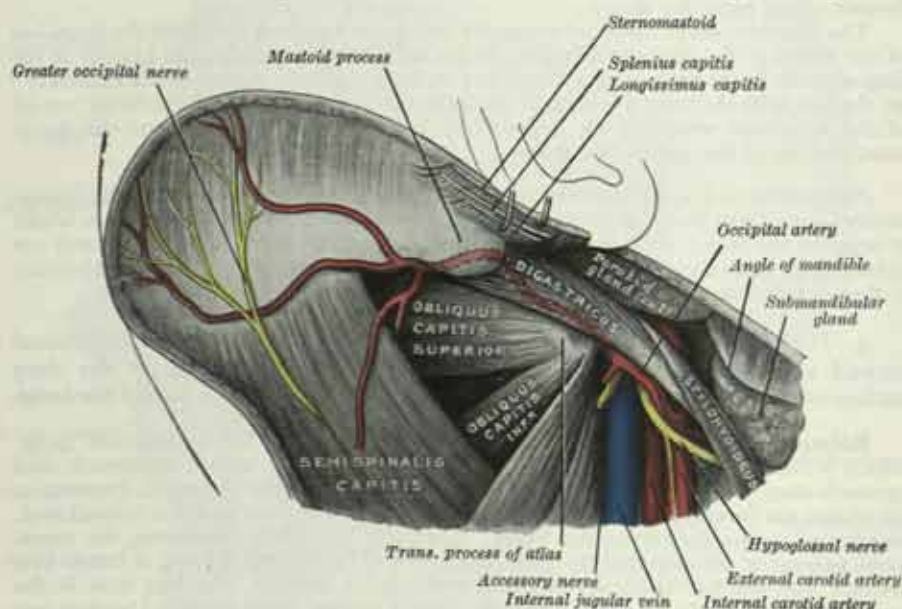
The **descending branch** (fig. 690) arises from the occipital artery as the latter lies on the *Obliquus superior*, and divides into superficial and deep branches. The superficial branch passes deep to the *Splenius*, and anastomoses with the superficial branch of the transverse cervical artery; the deep branch descends between the *Semispinales capitis et cervicis*, and anastomoses with the vertebral artery, and with the deep cervical artery, a branch of the costocervical trunk (fig. 694).

The **meningeal branches** enter the skull through the jugular foramen and the condylar canal, to supply the dura mater in the posterior fossa.

The **occipital branches**, which are the terminal branches, are distributed to the scalp, and reach as high as the vertex of the skull; they are very tortuous, and lie between the skin and the occipital belly of *Occipitofrontalis*, anastomosing with the artery of the opposite side and with the posterior auricular and temporal arteries, and supplying the occipital belly of *Occipitofrontalis*, the skin and the pericranium. One of the terminal branches may give off a meningeal twig, which passes through the parietal foramen.

6. The **posterior auricular artery** (fig. 689) is small and arises from the posterior surface of the external carotid artery immediately above the *Digastric* and

FIG. 690.—A drawing of a dissection to show the course of the occipital artery.



Stylohyoid. It ascends, under cover of the parotid gland, on the styloid process of the temporal bone, to the groove between the cartilage of the auricle and the mastoid process, where it divides into auricular and occipital branches.

As well as supplying small branches to the *Digastric*, *Stylohyoid*, *Sternomastoid*, and *parotid gland*, this vessel gives off additional branches:

The **stylomastoid artery** enters the stylomastoid foramen, and supplies the tympanic cavity, the mastoid antrum, the mastoid air-cells and the semicircular canals. In the young subject a branch from this vessel (termed the *posterior tympanic artery*) forms, with the anterior tympanic artery from the maxillary, a vascular circle which surrounds the tympanic membrane, and supplies small vessels to its deep surface.

The **auricular branch** ascends under cover of the *Auricularis posterior*, and ramifies on the cranial surface of the auricle; some of its branches pierce the auricle, and others curve round its margin to supply its lateral surface.

The **occipital branch** passes laterally across the front of the mastoid process and then backwards over the *Sternomastoid* to the occipital belly of the *Occipitofrontalis* muscle and to the scalp above and behind the ear; it anastomoses with the occipital artery.

7. The **superficial temporal artery** (fig. 684), the smaller terminal branch of the external carotid artery, begins in the parotid gland, behind the neck of the mandible, and crosses over the posterior root of the zygomatic process of the temporal bone; about 5 cm. above this process it divides into anterior and posterior branches.

Relations.—As it crosses the zygomatic process, it is covered by the Auricularis anterior; it is crossed in the substance of the parotid gland by the temporal and zygomatic branches of the facial nerve, and is accompanied in the scalp by the corresponding veins and by the auriculotemporal nerve, which lies immediately behind it.

It supplies some twigs to the parotid gland, the mandibular joint and the Masseter, and gives off certain named branches:

The **transverse facial artery** (fig. 689) arises from the superficial temporal artery before that vessel quits the parotid gland; it runs forwards through the substance of the gland, passes across the Masseter between the parotid duct and the zygomatic arch, accompanied by one or two branches of the facial nerve. It divides into numerous branches, which supply the parotid gland and duct, the Masseter, and the skin, and anastomose with the facial, masseteric, buccal, and infra-orbital arteries.

The **auricular branches** are distributed to the lobule and anterior portion of the auricle, and to the external auditory meatus.

The **zygomatic artery**, sometimes a branch of the middle temporal artery, runs along the upper border of the zygomatic arch between the two layers of the temporal fascia to the lateral angle of the orbit. It supplies branches to the Orbicularis oculi, and anastomoses with the lacrimal and palpebral branches of the ophthalmic artery.

The **middle temporal artery** arises immediately above the zygomatic arch, and, perforating the temporal fascia, gives branches to the Temporalis; it anastomoses with the deep temporal branches of the maxillary artery.

The **frontal (anterior) branch** runs tortuously upwards and forwards towards the frontal tuber; it supplies the muscles, skin and pericranium in this region, and anastomoses with its fellow of the opposite side, and with the supra-orbital and supra-trochlear arteries.

The **parietal (posterior) branch**, larger than the preceding vessel, curves upwards and backwards on the side of the head, lying superficial to the temporal fascia, and anastomosing with its fellow of the opposite side, and with the posterior auricular and occipital arteries.

Applied Anatomy.—As the superficial temporal artery crosses the zygomatic process it lies beneath the skin and fascia, and its pulsations may be readily felt during the administration of an anæsthetic, or in circumstances where the radial pulse is not available; it may be compressed easily against the bone in order to check bleeding from the temporal region of the scalp. It should be noted that this vessel and the other arteries to the scalp enter from below and are well protected by dense tissue. It is rarely found that they are all implicated in scalping injuries and their anastomoses are so free that so long as one is intact the detached scalp may be replaced with reasonable hope of its survival. When a flap is raised from this part of the head, for craniotomy, the incision should be shaped like a horseshoe, with its convexity upwards, so that the flap shall contain the superficial temporal artery, which ensures a sufficient supply of blood.

8. The **maxillary artery** (fig. 691), the larger terminal branch of the external carotid artery, arises behind the neck of the mandible and is at first imbedded in the parotid gland; it passes forwards between the neck of the mandible and the sphenomandibular ligament, and then running either superficial or deep to the lower head of the Lateral pterygoid, enters the pterygopalatine fossa between the two heads of that muscle. It may be divided into mandibular, pterygoid and pterygopalatine portions.

The **first or mandibular portion** passes horizontally forwards, between the neck of the mandible and the sphenomandibular ligament, where it lies parallel with and a little below the auriculotemporal nerve; it crosses the inferior alveolar nerve, and runs along the lower border of the Lateral pterygoid.

The **second or pterygoid portion** runs obliquely forwards and upwards under cover of the Temporal muscle, and superficial to the lower head of the Lateral pterygoid muscle; very frequently it lies deep to the latter, between it and the branches of the mandibular nerve, and in this case, before entering on the third part of its course, it often forms a wide loop which projects laterally between the two heads of the Lateral pterygoid muscle.

The **third or pterygopalatine portion** passes between the upper and lower heads of the Lateral pterygoid muscle, and through the pterygomaxillary fissure into the pterygopalatine fossa, where it lies in front of the pterygopalatine ganglion.

The maxillary artery is distributed to the upper and lower jaws, the muscles of mastication, the palate, nose and the cranial dura mater. Its branches may be divided into three groups, corresponding with its three portions.

THE BRANCHES OF THE FIRST (OR MANDIBULAR) PORTION OF THE
MAXILLARY ARTERY (fig. 691)

The **deep auricular artery**, a small branch, often arises in common with the anterior tympanic. It ascends in the substance of the parotid gland, behind the mandibular joint, pierces the cartilaginous or bony wall of the external auditory meatus, and supplies its cuticular lining and the outer surface of the tympanic membrane; it gives a branch to the mandibular joint.

The **anterior tympanic artery**, a small branch, ascends behind the mandibular joint, and enters the tympanic cavity through the petrotympanic fissure; it ramifies upon the tympanic membrane, and forms a vascular circle around it with the posterior tympanic branch of the stylomastoid artery; it anastomoses with small branches of the artery of the pterygoid canal and of the caroticotympanic branch from the internal carotid artery in the tympanic cavity.

The **middle meningeal artery** is the largest of the meningeal arteries. It ascends between the sphenomandibular ligament and the Lateral pterygoid muscle, and, passing between the two roots of the auriculotemporal nerve, may lie on the lateral surface of the Tensor veli palatini just before it enters the cranial cavity through the foramen spinosum of the sphenoid bone; it then runs forwards and laterally for a variable distance in a groove on the anterior part of the squamous part of the temporal bone, and divides into an anterior and a posterior branch. The *anterior branch*, the larger, crosses the greater wing of the sphenoid bone, reaches the groove, or canal, in the sphenoidal angle of the parietal bone, and then divides into branches which spread out between the dura mater and internal surface of the cranium, some passing upwards as far as the vertex, and others backwards to the occipital region. One branch runs upwards, grooving the parietal bone about 1.5 cm. behind the coronal suture. It corresponds, in a general way, to the line of the precentral sulcus of the brain. The *posterior branch* curves backwards on the squamous part of the temporal bone, and, reaching the lower border of the parietal bone some distance in front of its mastoid angle, divides into branches which supply the posterior part of the dura mater and cranium. The branches of the middle meningeal artery anastomose with the arteries of the opposite side, and with the anterior and posterior meningeal arteries.

The middle meningeal artery gives off the following branches within the cranial cavity: 1. Numerous small *ganglionic branches* supply the semilunar ganglion and the roots of the trigeminal nerve. 2. A *superficial petrosal branch* enters the hiatus for the greater petrosal nerve, gives twigs to the facial nerve and the tympanic cavity, and anastomoses with the stylomastoid branch of the posterior auricular artery. 3. A *superior tympanic artery* runs in the canal for the Tensor tympani, and supplies this muscle and the lining membrane of the canal. 4. *Temporal branches* pass through minute foramina in the greater wing of the sphenoid, and anastomose in the temporal fossa with the deep temporal arteries. 5. An *orbital branch* (p. 169) runs forwards and enters the orbit through the lateral part of the superior orbital fissure. It anastomoses with a recurrent meningeal branch of the lacrimal artery, and an enlargement of this anastomosis explains the occasional origin of the lacrimal from the middle meningeal artery.

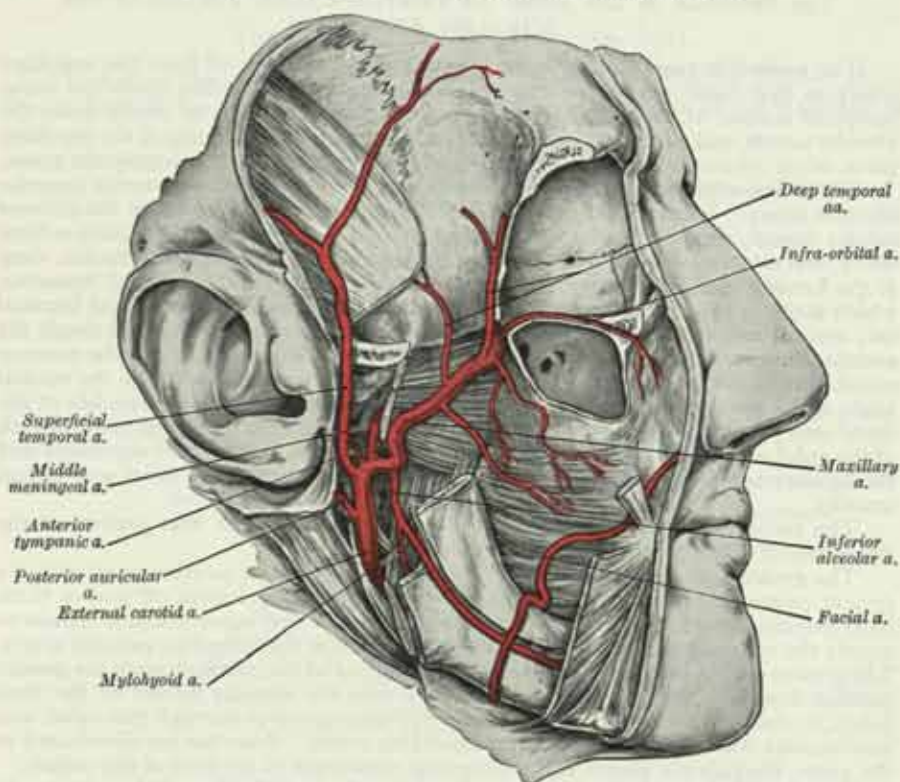
Surface Anatomy (fig. 754).—The *middle meningeal artery* enters the skull a little in front of the pre-auricular point and divides opposite a point 2 cm. above the middle of the zygomatic arch. From this situation the anterior branch runs first upwards and slightly forwards to the pterion and then turns upwards and backwards towards the mid-point between theinion and the nasion. The posterior division runs upwards and backwards towards the lambda.

Applied Anatomy.—The middle meningeal artery is of considerable surgical importance, as it may be torn in fractures of the temporal region of the skull, or, indeed, by injuries causing separation of the dura mater from the bone without fracture. The injury may be followed by considerable hæmorrhage between the bone and dura mater, which produces symptoms of compression of the brain, and requires trephining for its relief. As the compression implicates the motor region of the cortex, paralysis on the opposite side of the body forms the prominent symptom of the lesion.

The **accessory meningeal branch** may arise from the maxillary artery or from the middle meningeal artery. It enters the cranial cavity through the foramen ovale, and supplies branches to the semilunar ganglion and the dura mater.

The **inferior alveolar (dental) artery** descends posterior to the inferior alveolar nerve to the mandibular foramen on the medial surface of the ramus of the mandible. In this part of its course the artery lies between the bone on the lateral side, and the sphenomandibular ligament on the medial side. Before it enters the mandibular foramen, it gives off a *mylohyoid* branch, which pierces the sphenomandibular ligament, and descends with the mylohyoid nerve in the mylohyoid groove on the ramus of the mandible; it ramifies on the superficial surface of the Mylohyoid muscle and anastomoses with the submental branch of the facial artery. The inferior alveolar artery then runs in the mandibular canal, accompanied by the inferior alveolar nerve, and, opposite the first premolar tooth, divides into two branches,

FIG. 691.—The right maxillary (internal maxillary) artery.



An extensive dissection has been carried out, involving the removal of the parotid gland, the zygomatic arch, part of the ramus of the mandible, the lateral walls of the orbit and maxillary sinus and the orbital contents.

incisor and mental. The *incisor* branch is continued forwards below the incisor teeth as far as the median plane, where it anastomoses with the artery of the opposite side. Within the canal the inferior alveolar artery and its incisor branch give off a few twigs to the mandible, and a series of branches which correspond in number to the roots of the teeth; these enter the minute apertures at the extremities of the roots, and supply the pulp of the teeth. The *mental* branch escapes at the mental foramen, supplies the chin, and anastomoses with the submental and inferior labial arteries. Near its origin the inferior alveolar artery gives off a *lingual* branch, which descends with the lingual nerve and helps to supply the mucous membrane of the mouth.

THE BRANCHES OF THE SECOND (OR PTERYGOID) PORTION OF THE MAXILLARY ARTERY (fig. 691)

The **deep temporal branches**, an anterior and a posterior, ascend between the Temporalis and the pericranium; they supply the muscle, and anastomose with the middle temporal artery; the anterior communicates with the lacrimal artery by means

of small branches which perforate the zygomatic bone and greater wing of the sphenoid bone.

The **pterygoid branches**, irregular in their number and origin, supply the pterygoid muscles.

The **masseteric artery** is small and passes with the corresponding nerve behind the tendon of the Temporalis, and through the mandibular notch to the deep surface of the Masseter. In the substance of that muscle it anastomoses with the masseteric branches of the facial and with branches of the transverse facial artery.

The **buccal artery** is small and runs obliquely forwards with the buccal nerve, between the Medial pterygoid and the insertion of the Temporal muscle, to the outer surface of the Buccinator, to which it is distributed, anastomosing with branches of the facial and infra-orbital arteries.

THE BRANCHES OF THE THIRD (OR PTERYGOPALATINE) PORTION OF THE MAXILLARY ARTERY

The **posterior superior alveolar (dental) artery** is given off from the maxillary artery as that vessel enters the pterygopalatine fossa. Descending upon the infra-temporal surface of the maxilla, it divides into branches, some of which enter the alveolar canals, and supply the molar and premolar teeth and the lining of the maxillary sinus, while others are continued forwards on the alveolar process to supply the gums.

The **infra-orbital artery** often arises in conjunction with the posterior superior alveolar artery. It enters the orbital cavity through the posterior part of the inferior orbital fissure, runs along the infra-orbital groove and canal with the infra-orbital nerve, and emerges with the nerve on the face through the infra-orbital foramen, deep to the Levator labii superioris. Whilst in the canal, it gives off (*a*) **orbital branches**, which assist in supplying the Rectus inferior, the Obliquus inferior and the lacrimal sac, and (*b*) **anterior superior alveolar (dental) branches**, which descend through the anterior alveolar canals to supply the upper incisor and canine teeth and the mucous membrane of the maxillary sinus. On the face, some branches ascend to the medial angle of the eye and the lacrimal sac, anastomosing with the terminal branches of the facial artery; others run towards the nose, anastomosing with the dorsal nasal branch of the ophthalmic artery; and others descend between the Levator labii superioris and the Levator anguli oris, and anastomose with the facial, transverse facial and buccal arteries.

The remaining branches of the maxillary artery arise from that portion of the artery which is contained in the pterygopalatine fossa.

The **greater palatine artery** descends through the greater palatine canal with the greater palatine nerve from the sphenopalatine ganglion, and gives off two or three **lesser palatine arteries**, which are transmitted through the lesser palatine canals to supply the soft palate and tonsil, and to anastomose with the ascending palatine artery. The greater palatine artery emerges on the oral surface of the palate through the greater palatine foramen, runs forwards, in a groove near the alveolar border of the hard palate, to the incisive canal; its terminal part passes upwards through this canal, and anastomoses with a branch of the sphenopalatine artery. Branches are distributed to the gums, the palatine glands and the mucous membrane of the roof of the mouth.

The **pharyngeal branch** is very small; it runs backwards through the pharyngeal canal with the pharyngeal branch of the pterygopalatine ganglion, and is distributed to the roof of the nose and pharynx, to the sphenoidal air-sinus and the auditory tube.

The **artery of the pterygoid canal**, frequently a branch of the greater palatine artery, passes backwards along the pterygoid canal with the corresponding nerve. It is distributed to the upper part of the pharynx and to the auditory tube, and sends a small branch into the tympanic cavity.

The pharyngeal branch is medial, and the artery of the pterygoid canal lateral, to the pterygopalatine ganglion, while the trunk of the maxillary artery is in front of it.

The **sphenopalatine artery** is really the terminal part of the maxillary artery; it passes through the sphenopalatine foramen into the cavity of the nose at the posterior part of the superior meatus. Here it gives off its **posterior lateral nasal branches**, which ramify over the conchæ and meatuses, anastomose with the ethmoidal arteries and the nasal branches of the greater palatine artery, and assist in supplying the frontal, maxillary, ethmoidal and sphenoidal sinuses. Crossing the anterior part of the under surface of the sphenoid bone, the sphenopalatine artery ends on the nasal septum as the **posterior septal branches**, which anastomose with the ethmoidal arteries; one branch descends in a groove on the vomer to the incisive canal and anastomoses with the terminal ascending branch of the greater palatine artery, and with the septal branch of the superior labial artery.

Collateral Circulation.—After ligature of the common carotid, the collateral circulation can be perfectly established by the free communication which exists between the

carotid arteries of opposite sides, both outside and inside the cranium, and by enlargement of the branches of the subclavian artery. The chief communications outside the skull take place between the superior and inferior thyroid arteries, and between the deep cervical and descending branch of the occipital; the vertebral takes the place of the internal carotid within the cranium.

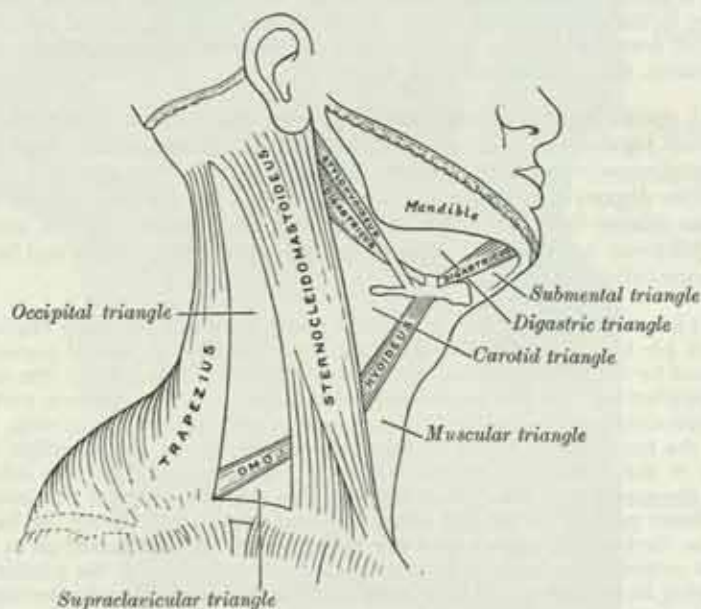
Wounds of the common carotid should be treated by suture whenever possible, because, after ligature of the vessel, symptoms of cerebral disturbance supervene in about twenty-five per cent. of cases.

After ligature of the external carotid artery the circulation is re-established by the free communication between most of the large branches of the artery (facial, lingual, superior thyroid, occipital) and the corresponding arteries of the opposite side, and by the anastomosis of its branches with those of the internal carotid artery, and of the occipital artery with branches of the subclavian, etc.

THE TRIANGLES OF THE NECK (fig. 692)

The side of the neck presents a somewhat quadrilateral outline, limited above by the base of the mandible, and a line drawn from the angle of the mandible to

FIG. 692.—The triangles of the neck.



the mastoid process; below, by the upper border of the clavicle; in front, by the anterior median line of the neck; behind, by the anterior margin of the Trapezius. This space is subdivided by the Sternomastoid muscle, which passes obliquely across the neck, from the sternum and clavicle below, to the mastoid process and occipital bone above. The area in front of this muscle is called the *anterior triangle* of the neck; that behind it, the *posterior triangle*.

THE ANTERIOR TRIANGLE OF THE NECK (figs. 692, 693)

The **anterior triangle** of the neck is bounded anteriorly by the anterior median line of the neck, posteriorly, by the anterior margin of the Sternomastoid; its base, directed upwards, is formed by the base of the mandible, and a line from the angle of the mandible to the mastoid process; its apex is below, at the sternum. This triangle may be subdivided into muscular, carotid, digastric and submental triangles.

The **muscular triangle** is bounded, in front, by the median line of the neck from the hyoid bone to the sternum; behind and below, by the anterior margin of the Sternomastoid; behind and above, by the superior belly of the Omohyoid.

The **carotid triangle** is limited, behind, by the Sternomastoid; in front and below, by the superior belly of the Omohyoid; and above, by the Stylohyoid and the posterior belly of the Digastric.

It is covered by the skin, superficial fascia, Platysma and deep fascia, ramifying in which are branches of the facial and the cutaneous cervical nerves. Its floor is formed by parts of the Thyrohyoid, Hyoglossus, and the Inferior and Middle constrictor muscles of the pharynx. When this space is dissected it is seen to contain the upper part of the common carotid artery, which divides opposite the superior border of the thyroid cartilage into the external and internal carotid arteries. These vessels are overlapped by the anterior margin of the Sternomastoid. The external and internal carotid arteries lie side by side, the external being the more anterior. The following branches of the external carotid artery are also encountered: the superior thyroid, running forwards and downwards; the lingual, forwards with an upward loop; the facial, forwards and upwards; the occipital, upwards and backwards; and the ascending pharyngeal, directly upwards on the medial side of the internal carotid. The veins encountered are those corresponding to the above-mentioned branches of the external carotid artery—viz. the superior thyroid, the lingual, common facial, ascending pharyngeal, and sometimes the occipital—all of which end in the internal jugular vein. The hypoglossal nerve crosses both the internal and external carotid arteries, curving round the origin of the lower Sternomastoid branch of the occipital artery; in this position it gives off the superior ramus of the ansa cervicalis, and the small nerve runs down in the anterior wall of the carotid sheath. On the medial side of the external carotid artery, below the hyoid bone, is the internal laryngeal nerve; and, still more inferiorly, the external laryngeal nerve.

It should be noted that many important structures in this region, such as the internal jugular vein, the vagus nerve, etc., lie entirely under cover of the Sternomastoid muscle and are therefore excluded from the triangle.

The **digastric triangle** is bounded, above, by the base of the mandible and a line drawn from its angle to the mastoid process; below and behind, by the posterior belly of the Digastric and the Stylohyoid; below and in front, by the anterior belly of the Digastric.

It is covered by the skin, superficial fascia, Platysma and deep fascia, ramifying in which are branches of the facial and anterior cutaneous cervical nerves. Its floor is formed by the Mylohyoid and Hyoglossus muscles. It is divided into an anterior and a posterior part by the stylomandibular ligament. The anterior part contains the submandibular gland, superficial to which is the (anterior) facial vein, while deep to it is the facial artery, which crosses the lower border of the mandible at the anterior edge of the Masseter; on the surface of the Mylohyoid are the submental artery and the mylohyoid artery and nerve. The posterior part of this triangle contains the lower part of the parotid gland; the external carotid artery, having passed deep to the Stylohyoid, curves over the upper border of the muscle so as to overlap to some extent its superficial surface where it ascends deep to the parotid gland before entering its substance; in this triangle the external carotid artery lies superficial to the internal carotid and crosses lateral to it; more deeply placed, and separated from the external carotid artery by the Styloglossus, the Stylopharyngeus and the glosso-pharyngeal nerve, are the internal carotid artery, the internal jugular vein and the vagus nerve.

The **submental triangle** is limited on each side by the anterior belly of the Digastric; its apex is at the mandible; its base is formed by the body of the hyoid bone, and its floor by the Mylohyoid muscles. It contains one or two lymph nodes and some small veins; the latter unite to form the anterior jugular vein.

THE POSTERIOR TRIANGLE OF THE NECK (fig. 692)

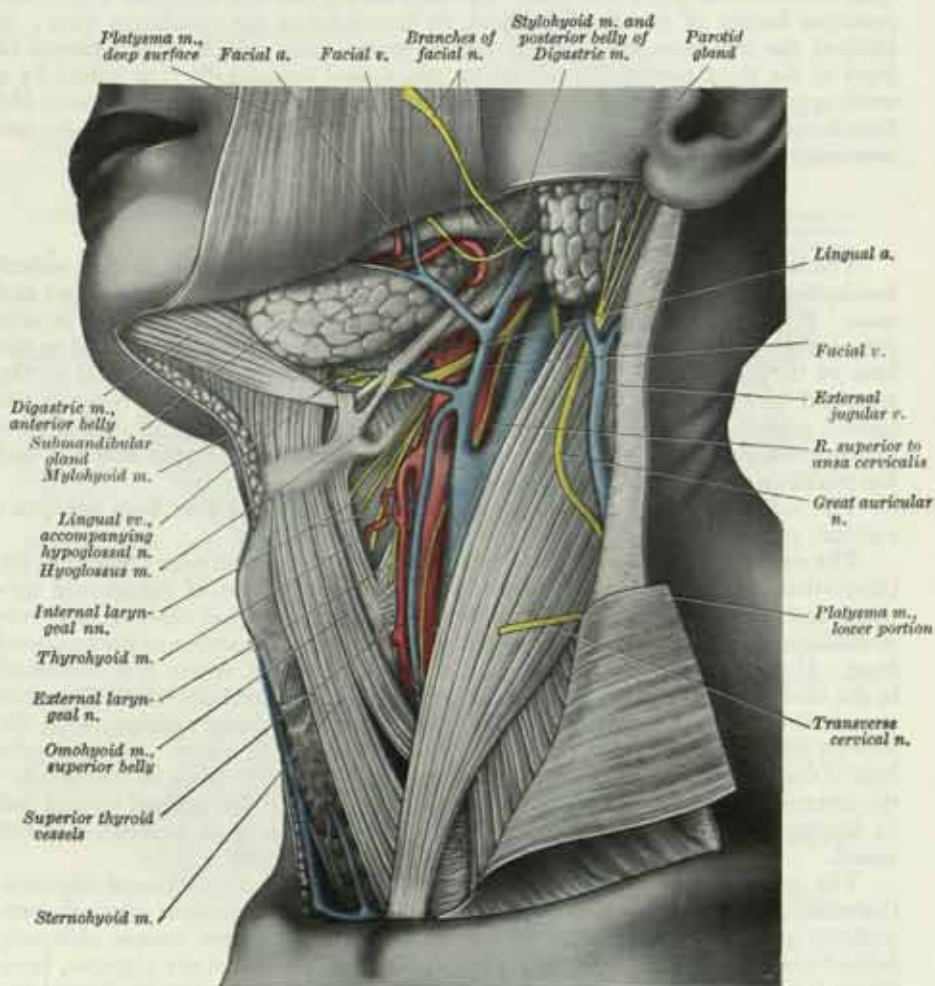
The **posterior triangle** of the neck is bounded, in front, by the Sternomastoid; behind, by the anterior margin of the Trapezius; its base is formed by the middle one-third of the clavicle; its apex is at the occipital bone between the attachments of the Sternomastoid and the Trapezius. The triangle is crossed, about 2.5 cm. above the clavicle, by the inferior belly of the Omohyoid, which divides the triangle into an occipital and a supraclavicular triangle.

The **occipital triangle**, the upper and larger division of the posterior triangle, is bounded in front by the Sternomastoid; behind, by the Trapezius; below, by

the Omohyoid. Its floor is formed from above downwards by the Splenius capitis, Levator scapulæ, and the Scalenus medius et posterior; sometimes a small part of the Semispinalis capitis is seen at the apex of the triangle. It is covered by the skin, the superficial and deep fasciæ, and below by the Platysma. The accessory nerve pierces the Sternomastoid and courses on the Levator scapulæ obliquely across the space to reach the under surface of the Trapezius; the cutaneous and muscular

FIG. 693.—A dissection of the anterior triangle of the left side of the neck.

The Platysma muscle has been divided transversely; its upper part has been turned upwards on to the face, exposing its deep surface: its lower part has been turned backwards, exposing both heads of the Sternomastoid muscle.



branches of the cervical plexus appear at the posterior border of the Sternomastoid; below, the supraclavicular nerves and the transverse cervical vessels and the upper part of the brachial plexus cross the space. A chain of lymph nodes is also found running along the posterior border of the Sternomastoid, from the mastoid process to the root of the neck.

The **supraclavicular triangle**, the lower and smaller division of the posterior triangle, is bounded, above, by the inferior belly of the Omohyoid; below, by the clavicle; its base is formed by the lower part of the posterior border of the Sternomastoid. Its floor consists of the first rib, the insertion of the Scalenus medius and the first digitation of the Serratus anterior. The size of this triangle varies with the extent of attachment of the clavicular portions of the Sternomastoid and Trapezius, and also with the level at which the inferior belly of the Omohyoid crosses the neck;

this level is lowered when the arm is raised, and raised when the arm is depressed. The triangle is covered by the skin, the superficial and deep fasciæ, and the Platysma, and crossed by the supraclavicular nerves. Just above the level of the clavicle, the third portion of the subclavian artery curves laterally and downwards from the lateral margin of the Scalenus anterior, across the first rib, to the axilla. The subclavian vein lies behind the clavicle, and is not usually seen in this space; but in some cases it rises as high as the artery, and has even been seen to accompany that vessel behind the Scalenus anterior. The brachial plexus of nerves lies partly above and partly behind the artery, and in close contact with it. The suprascapular vessels pass transversely behind the clavicle and are not, strictly speaking, in the triangle; and running in the same direction, but at a slightly higher level, are the transverse cervical artery and vein. The external jugular vein descends behind the posterior border of the Sternomastoid, to terminate in the subclavian vein; it receives the transverse cervical and suprascapular veins, which form a plexus in front of the third part of the subclavian artery, and occasionally it is joined by a small vein which crosses the clavicle from the cephalic vein. The small nerve to the Subclavius also crosses this triangle about its middle, and some lymph nodes are contained within the space.

THE INTERNAL CAROTID ARTERY

The **internal carotid artery** (fig. 694) supplies the greater part of the cerebral hemisphere, the eye and its accessory organs, and sends branches to the forehead and nose. It begins at the bifurcation of the common carotid artery, where it usually presents a localised dilatation, termed the carotid sinus (p. 736). It ascends to the base of the skull, and enters the cranial cavity through the carotid canal of the temporal bone. It then runs forward through the cavernous sinus, lying in the carotid groove on the side of the body of the sphenoid bone, and ends below the anterior perforated substance of the brain by dividing into the anterior and the middle cerebral arteries.

The internal carotid artery may accordingly be divided into four portions: cervical, petrous, cavernous and cerebral.

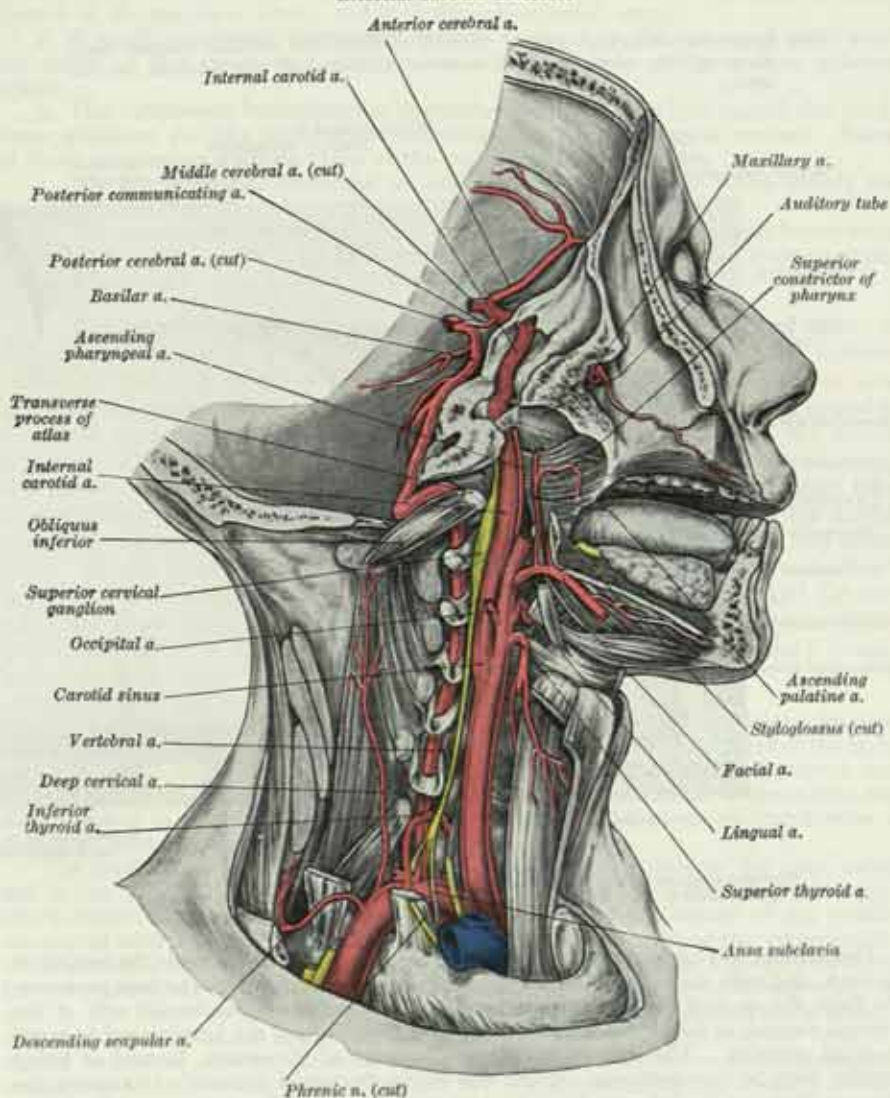
The cervical portion.—This portion of the internal carotid artery begins at the bifurcation of the common carotid artery, at the upper border of the thyroid cartilage, and ascends in front of the transverse processes of the upper three cervical vertebrae to gain the lower end of the carotid canal in the petrous portion of the temporal bone. It is comparatively superficial at its commencement, where it is contained in the carotid triangle, but after passing deep to the posterior belly of the Digastric muscle it lies on a much deeper plane. It presents important relations with the *internal jugular vein*, the *vagus nerve* and the *external carotid artery*. Except at the base of the skull, the internal jugular vein and the vagus nerve lie on its lateral side; the external carotid artery is at first anterior and medial to the internal carotid but on leaving the carotid triangle it curves backwards so as to lie superficial to the vessel.

The cervical portion of the internal carotid artery has many additional relations. *Posteriorly*, it rests on the Longus capitis muscle, but the superior cervical sympathetic ganglion intervenes and the superior laryngeal nerve crosses obliquely behind the vessel. *Medially*, the artery is related to the wall of the pharynx, from which it is separated by an interval containing some fat, connective tissue and the pharyngeal veins, the ascending pharyngeal artery and the superior laryngeal nerve. *Anterolaterally*, the internal carotid artery is covered throughout by the Sternomastoid muscle. In addition, *below the Digastric*, the hypoglossal nerve and the superior ramus of the ansa cervicalis, the lingual and facial veins are superficial to the artery. *At the level of the Digastric* the vessel is crossed by the Stylohyoid muscle and by the occipital and posterior auricular arteries. *Above the Digastric*, it is separated from the external carotid artery by the styloid process, the Styloglossus and Stylopharyngeus muscles, the glossopharyngeal nerve, the pharyngeal branch of the vagus and the deeper part of the parotid gland. At the base of the skull the glossopharyngeal, vagus, accessory and hypoglossal nerves are between the internal carotid artery and the internal jugular vein, which here lies posterior to the artery.

The petrous portion.—When the internal carotid artery enters the carotid canal in the petrous portion of the temporal bone, it first ascends, and then curves

forwards and medially. As it leaves the canal to enter the cranial cavity, it runs upwards and medially across the upper part of the foramen lacerum and above the fibrocartilage which it contains. Finally, it passes between the lingula and petrosal process of the sphenoid bone. The artery lies at first in front of the cochlea and tympanic cavity; it is separated from the latter and from the auditory tube by a thin, bony lamella, which is cribriform in the young subject, and often partly absorbed in old age. Further forwards it is separated from the semilunar

FIG. 694.—A dissection to show the whole course of the right vertebral and internal carotid arteries.



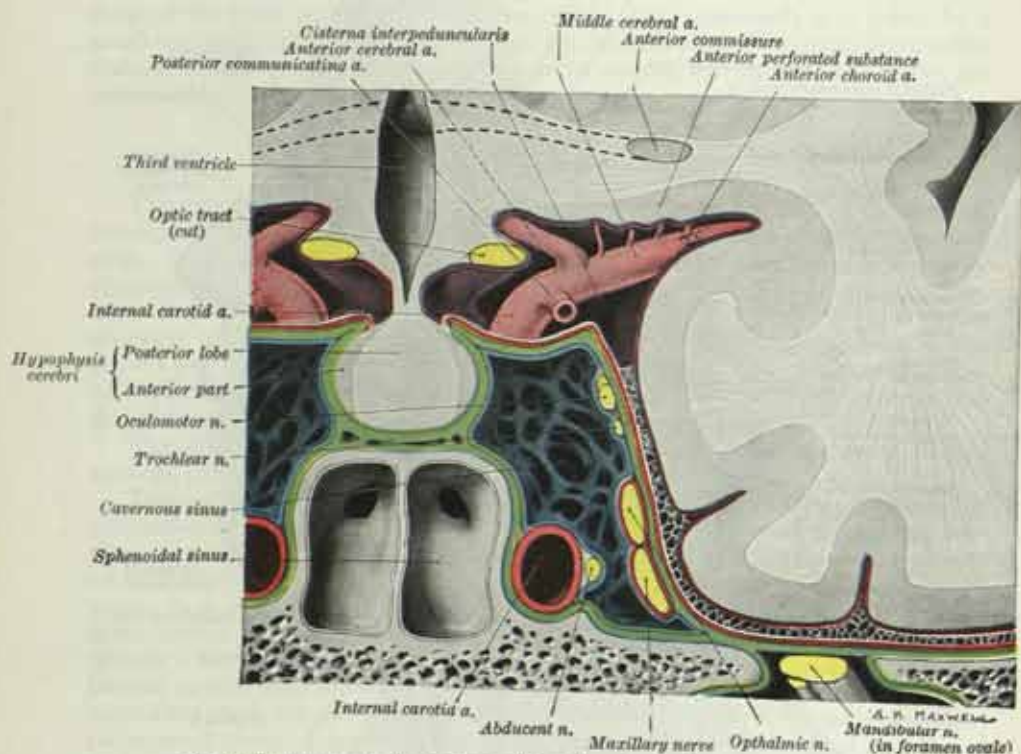
ganglion by a thin plate of bone, which forms the floor of the trigeminal impression and the roof of the horizontal portion of the carotid canal; frequently this bony plate is more or less deficient. The artery is surrounded by a number of small veins and by the carotid plexus of nerves, which is derived from the internal carotid branch of the superior cervical ganglion of the sympathetic trunk.

The **cavernous portion** of the internal carotid artery (fig. 695) is situated in the cavernous sinus, but is covered by the lining endothelium of the sinus. It at first ascends towards the posterior clinoid process, then passes forwards on the side of the body of the sphenoid, and again curves upwards on the medial side of the anterior clinoid process, and perforates the dura mater forming the

roof of the sinus; occasionally the anterior and middle clinoid processes form a bony ring round the artery. The cavernous portion of the artery is surrounded by a sympathetic plexus, and the oculomotor, trochlear, ophthalmic and abducent nerves (fig. 695) are on its lateral side.

The cerebral portion.—After perforating the dura mater at the medial side of the anterior clinoid process, the internal carotid artery turns backwards below the optic nerve, and then passes between the optic and oculomotor nerves to the anterior perforated substance at the medial end of the lateral cerebral sulcus, where it divides into the anterior and middle cerebral arteries.

FIG. 695.—An obliquely coronal section through the middle cranial fossa showing the cavernous and cerebral portions of the internal carotid artery.



Pia mater=mauve: Arachnoid mater=white: fibrous layer of dura mater=green: mesothelium of dura mater=red: endothelium of cavernous sinus=light blue.

Peculiarities.—The length of the internal carotid artery varies with the length of the neck, and with the point of bifurcation of the common carotid. It arises occasionally from the arch of the aorta, and then has been found on the medial side of the external carotid, as far as the larynx, where it crossed behind the latter vessel to reach its usual position. The course of the cervical part of the artery, instead of being straight, may be very tortuous. When this occurs the vessel approaches nearer to the pharynx than usual, and may lie very close to the lateral side of the tonsil.* A few instances are recorded in which it was absent.

Surface Anatomy.—The internal carotid corresponds to a broad line drawn upwards from the termination of the common carotid to the posterior border of the neck of the mandible (fig. 687).

Branches.—No branches arise from the cervical portion of the internal carotid artery. Those from the other portions are:

- | | |
|--------------------------|---|
| From the petrous portion | { 1. Caroticotympanic.
2. Pterygoid. |
|--------------------------|---|

* Consult an article by John Cairney, *J. Anat.*, 59, 1925.

From the cavernous portion

3. Cavernous.

4. Hypophyseal.

5. Meningeal.

6. Ophthalmic.

7. Anterior cerebral.

8. Middle cerebral.

9. Posterior communicating.

10. Anterior choroid.

From the cerebral portion

1. The **caroticotympanic branch** is small ; it enters the tympanic cavity through a foramen in the wall of the carotid canal, and anastomoses with the anterior tympanic branch of the maxillary artery, and with the stylomastoid artery.

2. A small, inconstant **pterygoid branch** passes into the pterygoid canal with the nerve of that canal, and anastomoses with a branch of the greater palatine artery.

3. The **cavernous branches** are numerous small vessels which supply the semi-lunar ganglion, and the walls of the cavernous and inferior petrosal sinuses. Some of them anastomose with branches of the middle meningeal artery.

4. The **hypophyseal branches** are one or two minute vessels which supply the hypophysis cerebri.

5. The **meningeal branch** is a minute branch which passes over the lesser wing of the sphenoid to supply the dura mater of the anterior cranial fossa ; it anastomoses with the meningeal branch from the posterior ethmoidal artery.

6. The **ophthalmic artery** (fig. 696) arises from the internal carotid artery as that vessel emerges from the cavernous sinus on the medial side of the anterior clinoid process ; it enters the orbital cavity through the optic canal, below and lateral to the optic nerve. In the orbital cavity it runs for a short distance lateral to the optic nerve and medial to the oculomotor and abducent nerves, the ciliary ganglion and the Rectus lateralis. It next crosses obliquely above the optic nerve and below the Rectus superior to reach the medial wall of the orbit. It then runs forwards between the Obliquus superior and the Rectus medialis, and, at the medial end of the upper eyelid, divides into two branches, named *supratrochlear* and *dorsal nasal*. As the artery crosses the optic nerve it is accompanied by the nasociliary nerve, and is separated from the frontal nerve by the Rectus superior and Levator palpebræ superioris ; the terminal part of the artery is accompanied by the infra-trochlear nerve. In about 15 per cent. of subjects the ophthalmic artery crosses below the optic nerve.

Branches.—The **central artery of the retina**, the first and one of the smallest branches of the ophthalmic artery, arises from that vessel whilst it lies below the optic nerve. It runs for a short distance within the dural sheath of the optic nerve, and about 1.25 cm. behind the eyeball it pierces the inferomedial surface of the nerve, and runs forward to the retina in the centre of the nerve. Its mode of distribution is described with the anatomy of the eye (p. 1247).

The **lacrimal artery** arises from the ophthalmic artery close to the optic canal, and is one of its largest branches ; sometimes it is given off before the ophthalmic artery enters the orbit ; occasionally its place is taken by a branch of the middle meningeal artery (p. 748). It accompanies the lacrimal nerve along the upper border of the Rectus lateralis, and supplies the lacrimal gland. Its terminal branches, escaping from the gland, are distributed to the eyelids and conjunctiva : of those supplying the eyelids, two are of considerable size and are named the **lateral palpebral arteries** ; they run medially in the upper and lower lids respectively and anastomose with the medial palpebral arteries. The lacrimal artery gives off one or two **zygomatic branches**, one of which passes through the zygomatico-temporal foramen to the temporal fossa, and anastomoses with the deep temporal arteries ; another appears on the cheek through the zygomaticofacial foramen and anastomoses with the transverse facial artery. A **recurrent meningeal branch** passes backwards through the lateral part of the superior orbital fissure and anastomoses with a branch of the middle meningeal artery.

The **muscular branches** frequently spring from a common trunk. They consist of a superior and an inferior group, and most of them accompany the branches of the oculomotor nerve. The inferior group, more constantly present, gives off most of the anterior ciliary arteries. Additional muscular branches are derived from the lacrimal and supra-orbital arteries, or from the trunk of the ophthalmic artery.

The **ciliary arteries** are divisible into three groups, long and short posterior, and anterior.

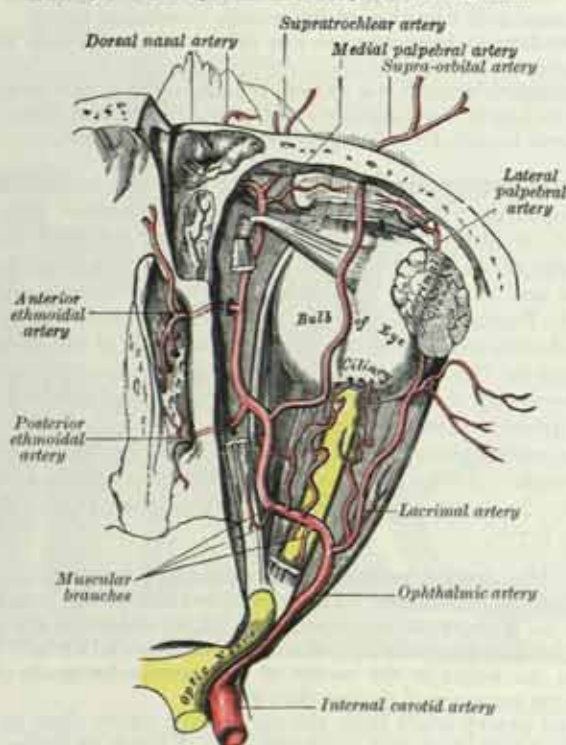
The **long posterior ciliary arteries**, two in number, pierce the posterior part of the sclera a short distance from the entrance of the optic nerve. Their distribution is described on p. 1242.

The **short posterior ciliary arteries**, about seven in number, pass forwards around the optic nerve to the posterior part of the eyeball, and, after dividing into from fifteen to twenty branches, pierce the sclera around the entrance of the nerve, and supply the choroid coat and the ciliary processes. At the entrance of the optic nerve they anastomose with twigs of the central artery of the retina, and at the ora serrata with branches of the long posterior and anterior ciliary arteries.

The **anterior ciliary arteries** are derived from the muscular branches of the ophthalmic artery; they run to the front of the eyeball in company with the tendons of the Recti, form a vascular zone beneath the conjunctiva, and then pierce the sclera a short distance from the sclerocorneal junction and end in the greater arterial circle (p. 1242).

The **supra-orbital artery** leaves the ophthalmic artery as that vessel crosses the optic nerve. It ascends medial to the Rectus superior and Levator palpebræ

FIG. 696.—The ophthalmic artery and its branches.



superioris and, meeting the supra-orbital nerve, accompanies it between the periosteum and Levator palpebræ superioris to the supra-orbital foramen; passing through this foramen, it divides into superficial and deep branches, which supply the skin, muscles and pericranium of the forehead, anastomosing with the supratrochlear artery, the frontal branch of the superficial temporal artery, and the artery of the opposite side. In the orbit it supplies twigs to the Rectus superior and the Levator palpebræ, and sends a branch across the pulley of the Obliquus superior, to the parts at the medial angle of the eye. At the supra-orbital foramen it frequently sends a branch to the diploë of the frontal bone.

The **posterior ethmoidal artery** runs through the posterior ethmoidal canal, supplies the posterior ethmoidal sinuses, and, entering the cranium, gives off a meningeal branch to the dura mater, and nasal branches which descend into the nasal cavity through the cribriform plate of the ethmoid bone, to anastomose with branches of the sphenopalatine artery.

The **anterior ethmoidal artery** accompanies the anterior ethmoidal nerve through the anterior ethmoidal canal, supplies the anterior and middle ethmoidal and frontal sinuses, and, entering the cranium, gives off a meningeal branch to the dura mater, and nasal branches; the latter descend into the nasal cavity with the anterior ethmoidal nerve and, running along the groove on the inner surface of the nasal bone, supply

twigs to the lateral wall and septum of the nose, and a terminal branch which appears on the dorsum of the nose between the nasal bone and the upper nasal cartilage.

The **meningeal branch** is a small branch which passes backwards through the superior orbital fissure to the middle cranial fossa, and anastomoses with the middle and accessory meningeal arteries.

The **medial palpebral arteries**, two in number, superior and inferior, arise from the ophthalmic artery below the pulley of the Obliquus superior. They descend behind the lacrimal sac, and enter the eyelids, where each divides into two branches which course laterally along the edges of the tarsi, thus forming two arches (a superior and an inferior) in each eyelid. The superior palpebral artery anastomoses with the supra-orbital artery; and, at the lateral part of the eyelid, with the zygomatic branch of the superficial temporal artery, and with the upper of the two lateral palpebral branches of the lacrimal artery. The inferior palpebral artery anastomoses at the lateral part of the eyelid with the lower of the two lateral palpebral branches of the lacrimal artery and with the transverse facial artery, and at the medial part of the eyelid with a twig from the facial artery; from this last anastomosis a branch passes to the nasolacrimal duct, ramifying in its mucous membrane.

The **supratrochlear artery**, one of the terminal branches of the ophthalmic artery, leaves the orbital opening at its upper medial angle, with the supratrochlear nerve, and, ascending on the forehead, supplies the skin, muscles and pericranium, anastomosing with the supra-orbital artery and with the artery of the opposite side.

The **dorsal nasal artery**, the other terminal branch of the ophthalmic artery, emerges from the orbit between the trochlea of the Obliquus superior and the medial palpebral ligament, and, after giving a twig to the upper part of the lacrimal sac, divides into two branches, one of which anastomoses with the terminal part of the facial artery; the other runs along the dorsum of the nose, supplies its outer surface, and anastomoses with the artery of the opposite side, and with the lateral nasal branch of the facial artery.

7. The **anterior cerebral artery** (figs. 697, 698, 699) arises from the internal carotid artery, at the medial end of the lateral cerebral sulcus. It passes forwards and medially above the optic nerve, to the commencement of the longitudinal fissure. Here it comes into close relationship with the opposite artery and is joined to it by a short transverse trunk (sometimes duplicated) named the anterior communicating artery. From this point, the two anterior cerebral arteries run side by side in the longitudinal cerebral fissure, curving round the genu of the corpus callosum, and running backwards along the upper surface of this structure to its posterior extremity, where they end by anastomosing with the posterior cerebral arteries.

The **anterior communicating artery** has an average length of about 4 mm. and connects the two anterior cerebral arteries across the commencement of the longitudinal fissure; in about 7 per cent. of subjects it is double. It gives off a few anteromedial central branches (p. 762).

In its course the anterior cerebral artery gives off central and cortical branches.

The **central branches** are a group of small arteries which arise from the commencement of the anterior cerebral artery; they pierce the anterior perforated substance and lamina terminalis, and supply the rostrum of the corpus callosum, the septum lucidum, the anterior part of the putamen of the lentiform nucleus and the head of the caudate nucleus. The **cortical branches** are distributed to the areas from which they take their names. The **orbital branches**, two or three in number, are distributed to the orbital surface of the frontal lobe, where they supply the olfactory lobe, gyrus rectus and medial orbital gyrus. The **frontal branches** supply the corpus callosum, the cingulate gyrus, the medial frontal gyrus and the paracentral lobule, and send twigs over the superomedial border of the cerebral hemisphere to the superior and middle frontal gyri and the upper part of the precentral gyrus. The **parietal branches** supply the precuneus and adjacent lateral surface of the hemisphere.

8. The **middle cerebral artery** (figs. 697, 698, 699), the largest branch of the internal carotid artery, runs at first laterally in the lateral cerebral sulcus and then backwards and upwards on the surface of the insula, where it divides into branches which are distributed to the insula and to the lateral surface of the cerebral hemisphere.

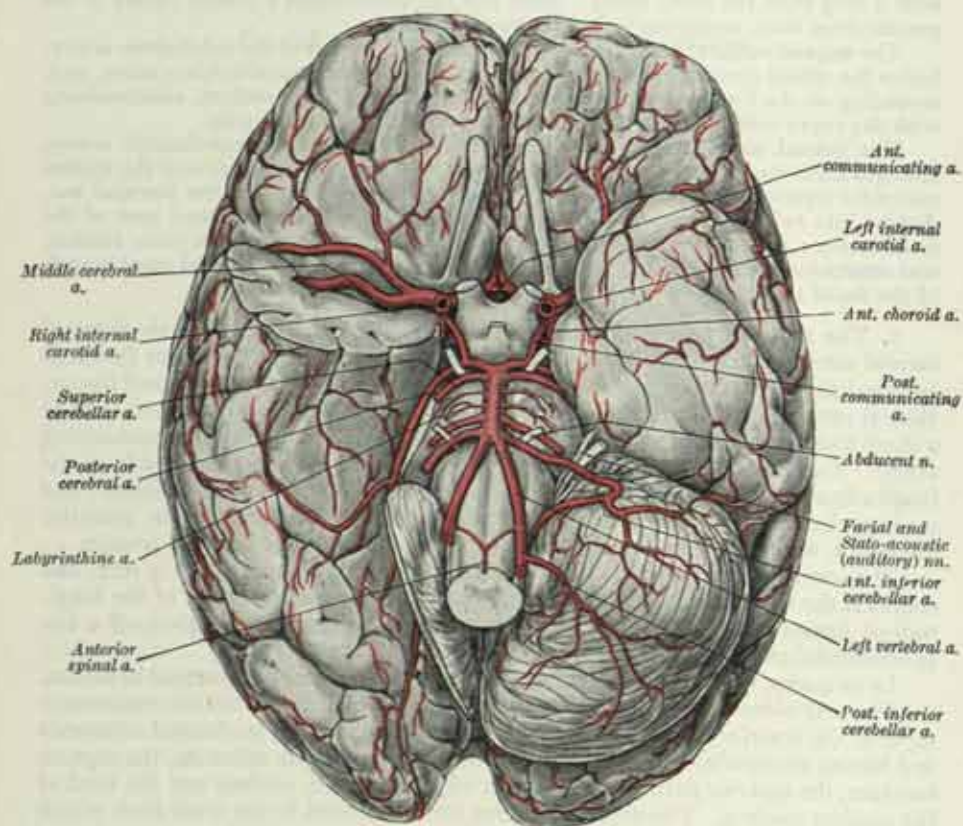
The branches of the middle cerebral artery are central and cortical.

The **central branches** comprise a group of small arteries which arise from the commencement of the middle cerebral artery and enter the substance of the brain through the anterior perforated substance.* They are arranged in two sets:

* J. L. Shellshear, *J. Anat.*, 55, 1920.

one, termed the *medial striate*, ascends through the lentiform nucleus, and supplies it, the caudate nucleus, and the internal capsule; the other, termed the *lateral striate*, ascends over the lower part of the lateral aspect of the lentiform nucleus and then, bending medially, traverses the nucleus and the internal capsule to reach and supply the caudate nucleus. One artery of this group is larger than the rest, and of special importance as being the artery in the brain most frequently ruptured; it has been termed by Charcot the '*artery of cerebral hæmorrhage*'. Of the *cortical branches*, the *orbital branches* supply the inferior frontal gyrus and the lateral part of the orbital surface of the frontal lobe. The *frontal* supplies the precentral and the middle frontal gyrus. The *parietal branches*, two in number, are distributed to the postcentral gyrus, the lower part of the superior parietal lobule, and the whole of

FIG. 697.—The arteries at the base of the brain.



The right temporal pole and most of the right hemisphere of the cerebellum have been removed.

the inferior parietal lobule. The *temporal branches*, two or three in number, are distributed to the lateral surface of the temporal lobe.

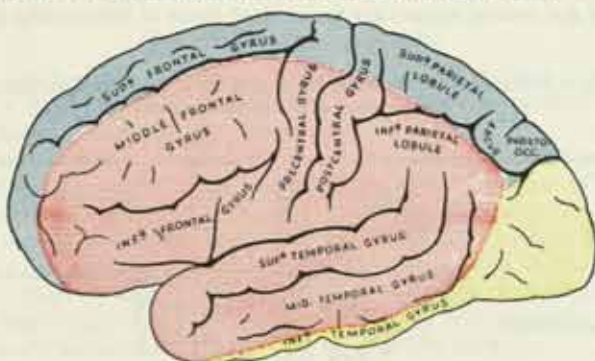
9. The **posterior communicating artery** (figs. 697, 700) runs backwards from the internal carotid above the oculomotor nerve, and anastomoses with the posterior cerebral, a branch of the basilar artery. It is usually a small vessel, but is occasionally so large that the posterior cerebral may be considered as arising from the internal carotid rather than from the basilar. It is frequently larger on one side than on the other. From its posterior half are given off several small *central branches*, which, with similar vessels from the posterior cerebral artery, pierce the posterior perforated substance and supply the medial surface of the thalamus and the walls of the third ventricle.

10. The **anterior choroid artery**,* a small but constant branch, arises from the internal carotid, near the posterior communicating artery. Passing backwards

* Consult articles by A. A. Abbie, *J. Anat.*, 67, 1933, and *J. Anat.*, 68, 1934.

above the medial part of the uncus, it crosses the optic tract and comes into relation with the basis pedunculi, to which it gives several minute branches. It then turns laterally, again crossing the optic tract, and comes into relation with the lateral aspect of the lateral geniculate body, to which it supplies a number of branches. Finally it enters the inferior horn of the lateral ventricle through the choroidal fissure

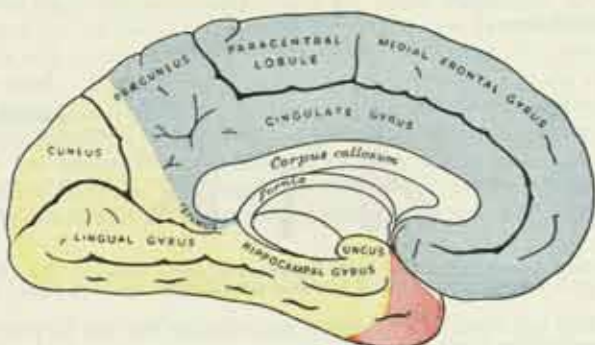
FIG. 698.—The lateral surface of the cerebral hemisphere, showing the areas supplied by the cerebral arteries. In this and the next figure the areas supplied by the anterior cerebral artery are coloured *blue*; those by the middle cerebral artery, *pink*; and those by the posterior cerebral artery, *yellow*.



and terminates in the choroid plexus. In addition, it supplies branches to the globus pallidus, the posterior limb of the internal capsule, the optic radiation, the optic tract, the hippocampus and the fimbria.

The *circulus arteriosus*.—A considerable part of the brain is supplied by the two vertebral arteries (p. 767), and a remarkable anastomosis, named the *circulus arteriosus*, exists between these vessels and the two internal carotid arteries. This

FIG. 699.—The medial surface of the cerebral hemisphere, showing the areas supplied by the cerebral arteries (see description of fig. 698).



circle is situated in the cisterna interpeduncularis at the base of the brain, and encloses the optic chiasma and the structures in the interpeduncular fossa (p. 1019). It is formed as follows: in front, the two anterior cerebral arteries are joined to each other by the anterior communicating artery; behind, the basilar artery (p. 768), divides into the two posterior cerebral arteries, each of which is joined to the internal carotid artery of the same side by the posterior communicating artery (fig. 700).

THE ARTERIES OF THE BRAIN

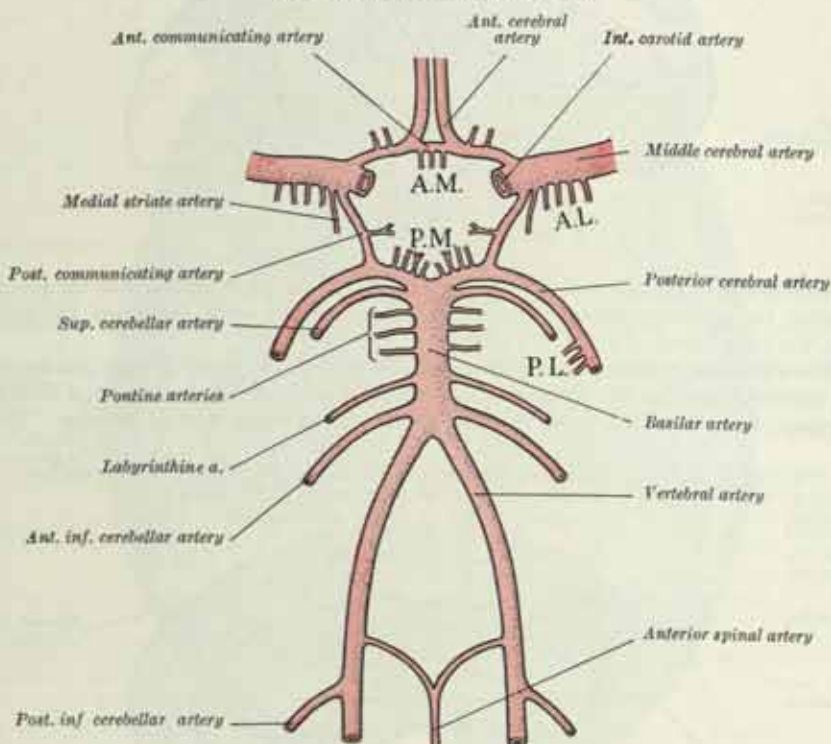
The mode of distribution of the vessels of the brain has an important bearing upon some pathological lesions which may occur in this part of the nervous system.

The arteries which supply the brain give origin to two systems of vessels. One of these is named the **central system**, and its vessels supply the thalami and corpora striata; the other is the **cortical system**, and its vessels ramify in the pia mater and

supply the cortex and subjacent brain-substance. These two systems are independent of each other and do not communicate at any point of their peripheral distribution, and there is between the parts supplied by them a borderland of diminished nutritive activity where, it is said, softening of the brain is especially liable to occur.

The **central system**.—All the vessels of this system are given off from the *circulus arteriosus*, or from the vessels close to it. They form six principal groups: (i) an **anteromedial group**, derived from the anterior cerebral and anterior communicating arteries; (ii) a **posteromedial group**, from the posterior cerebral and posterior communicating arteries; (iii and iv) right and left **anterolateral groups**, from the middle cerebral arteries; and (v and vi) right and left **posterolateral groups**, from the posterior cerebral arteries after they have wound round the cerebral peduncles. The vessels of the central system are larger than those of the cortical system, and are

FIG. 700.—A diagram of the arteries at the base of the brain, showing the constitution of the *arterial circle*.



A.L. Anterolateral central branches. A.M. Anteromedial central branches. P.L. Posterolateral central branches. P.M. Posteromedial central branches.

known as 'terminal' or 'end' arteries—that is to say, vessels which from their origin to their termination neither supply nor receive any anastomotic branch, so that, through any one vessel only a limited area of the thalamus or corpus striatum can be injected.

The **cortical system**.—The vessels of this system are the terminal branches of the anterior, middle and posterior cerebral arteries. They divide in the substance of the pia mater, give off branches which penetrate the brain-cortex perpendicularly, and are divisible into two classes, long and short. The **long** or **medullary arteries** pass through the grey matter and penetrate the subjacent white matter to the depth of 3 or 4 cm., without intercommunicating, and thus constitute so many independent small systems. The **short vessels** are confined to the cortex, where they form with the long vessels a compact network in the middle zone of the grey matter, the outer and inner zones being sparingly supplied with blood. The vessels of the cortical system are not so strictly 'terminal' as those of the central system,* but they approach this type closely, for, although neighbouring vessels anastomose with one another freely on the surface of the brain, they become end arteries as soon as they pierce its substance.

* S. Sunderland, *J. Anat.*, 73, 1938.

THE ARTERIES OF THE UPPER LIMB

The artery which supplies the upper limb runs as a single trunk as far as the elbow; but it is differently named, according to the regions it traverses. From its origin to the outer border of the first rib it is termed *subclavian*; from the outer border of the first rib to the lower border of the tendon of the Teres major it is named *axillary*; and from the lower border of the Teres major to a point opposite the neck of the radius it is called *brachial*.

THE SUBCLAVIAN ARTERIES

The right subclavian artery arises from the brachiocephalic trunk; the left, from the arch of the aorta. The vessels, therefore, in the first parts of their courses, differ in their length, direction and relations.

To facilitate description, each subclavian artery is divided into three parts; the first extends from the origin of the vessel to the medial border of the Scalenus anterior, the second lies behind this muscle, and the third runs from the lateral margin of the muscle across the first rib to its outer border, where it becomes the axillary artery; each artery arches over the cervical portion of the pleura. The first portions of the two vessels differ from one another in their origin, course and relations, and therefore require separate descriptions. The relations of the second and third parts are almost alike on the two sides of the neck.

THE FIRST PART OF THE RIGHT SUBCLAVIAN ARTERY (figs. 701, 703)

The **first part** of the **right subclavian artery** arises from the brachiocephalic trunk, behind the upper part of the right sternoclavicular joint, and passes upwards and laterally to the medial margin of the Scalenus anterior. It ascends, on an average, about 2 cm. above the clavicle, but the height it reaches varies considerably.

Relations.—*In front*, the artery is covered by the skin, superficial fascia, Platysma, medial supraclavicular nerves, deep fascia, the clavicular origin of the Sternomastoid, the Sternohyoid and Sternothyroid. At its origin it is placed behind the origin of the right common carotid artery; more laterally it is crossed by the vagus nerve and the cardiac branches of the vagus and sympathetic, and by the internal jugular and vertebral veins; the subclavian loop of the sympathetic trunk encircles the vessel. The anterior jugular vein is directed laterally in front of the artery, but is separated from it by the Sternohyoid and Sternothyroid. *Below and behind*, the artery is related to the pleura and the apex of the lung, but it is separated from them by the suprapleural membrane (p. 1327), the ansa subclavia, a small accessory vertebral vein (p. 844), and the right recurrent laryngeal nerve, which winds round the lower and posterior part of the vessel.

THE FIRST PART OF THE LEFT SUBCLAVIAN ARTERY (figs. 680, 683, 685, 702)

The **first part** of the **left subclavian artery** arises from the arch of the aorta, behind the left common carotid, usually at the level of the disc between the third and fourth thoracic vertebrae; it ascends to the root of the neck and then arches laterally as far as the medial border of the Scalenus anterior.

Relations. (1) **Within the thorax.**—It is related, *in front*, to the left common carotid artery and the commencement of the left brachiocephalic vein, from which it is separated by the left vagus, cardiac and phrenic nerves. Superficial to these structures, the anterior margin of the left lung and pleura and the Sternothyroid and Sternohyoid muscles intervene between the vessel and the upper, left portion of the manubrium sterni. *Behind*, it lies, successively, on the left edge of the oesophagus, the thoracic duct and the Longus cervicis, and it is in contact posterolaterally with the left lung and pleura. *Medially* it is related, successively, to the trachea, the left recurrent laryngeal nerve, the oesophagus and the thoracic duct. *Laterally* the artery grooves the mediastinal surface of the left lung and pleura, and these structures, as already indicated, tend to encroach on its anterior and posterior aspects.

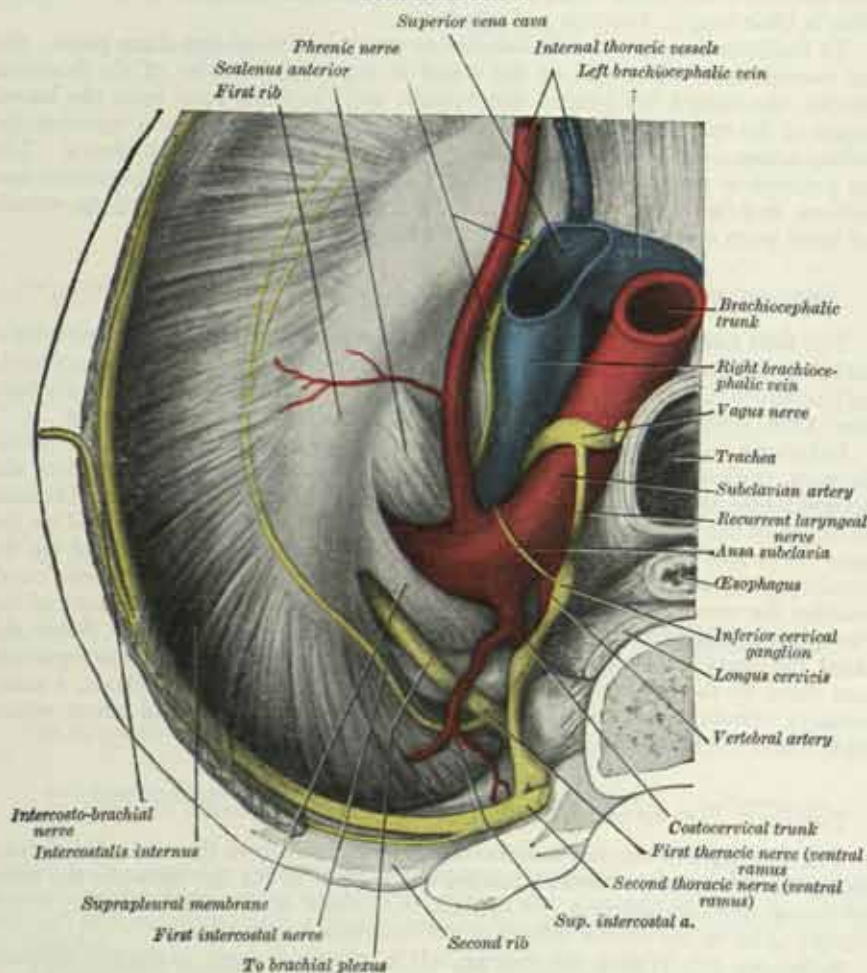
(2) **In the neck.**—Near the medial border of the Scalenus anterior the artery is crossed *anteriorly* by the left phrenic nerve and the terminal part of the thoracic

duct. Otherwise the relations are the same as those previously described for the first part of the right subclavian artery. *Posteriorly* and *inferiorly*, the relations of the two vessels are identical, but the left recurrent laryngeal nerve, which is related to the left subclavian artery in the thorax, is not related to its cervical portion.

THE SECOND AND THIRD PARTS OF THE SUBCLAVIAN ARTERY
(figs. 703, 704)

The **second portion** of the subclavian artery lies behind the *Scalenus anterior*; it is very short, and forms the highest part of the arch described by the vessel.

FIG. 701.—Structures in relation with the cervical pleura of the right side.
Seen from below.



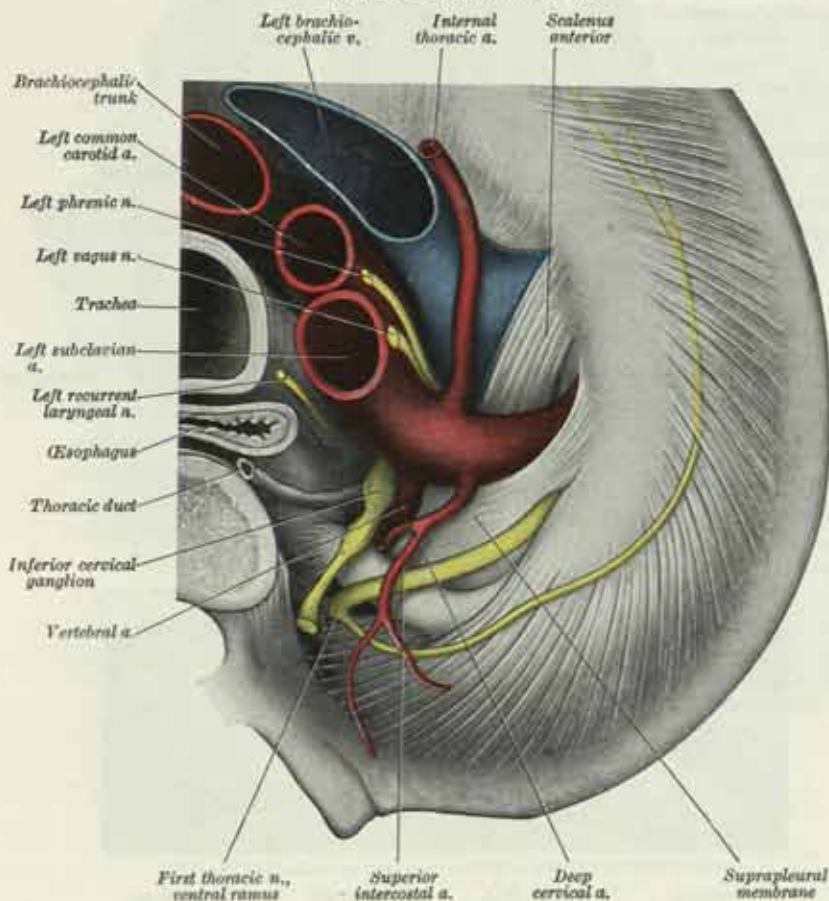
Relations.—*In front* of it are the skin, superficial fascia, *Platysma*, deep cervical fascia, *Sternomastoid* and *Scalenus anterior*. On the right side of the neck the phrenic nerve is separated from the second part of the artery by the *Scalenus anterior*, while on the left side it crosses the first part of the artery close to the medial edge of the muscle. *Behind* and *below* the vessel are the suprapleural membrane, pleura and lung, and the lower trunk of the brachial plexus; *above*, the upper and middle trunks of the brachial plexus. The subclavian vein lies below and in front of the artery, separated from it by the *Scalenus anterior* (fig. 704).

The **third portion** of the subclavian artery runs downwards and laterally from the lateral margin of the *Scalenus anterior* to the outer border of the first rib, where

it becomes the axillary artery. This is the most superficial portion of the vessel, and is contained in the supraclavicular triangle (p. 753).

Relations.—*In front* of it are the skin, the superficial fascia, the Platysma, the supraclavicular nerves and the deep cervical fascia. The external jugular vein crosses its medial part and receives the suprascapular, transverse cervical and anterior jugular veins, which frequently form a plexus in front of the artery. The nerve to the Subclavius descends behind the veins and in front of the artery. The terminal part of the artery lies behind the clavicle and the Subclavius, and is crossed by the suprascapular vessels. The subclavian vein is in front of, and at a slightly lower level than, the artery. The lower trunk of the brachial plexus lies *behind* the artery and intervenes between it and the Scalenus medius. *Above*, and

FIG. 702.—Structures in relation with the cervical pleura of the left side. Seen from below.



to its *lateral side*, are the upper and middle trunks of the brachial plexus, and the inferior belly of the Omohyoid. *Below*, it rests on the upper surface of the first rib.

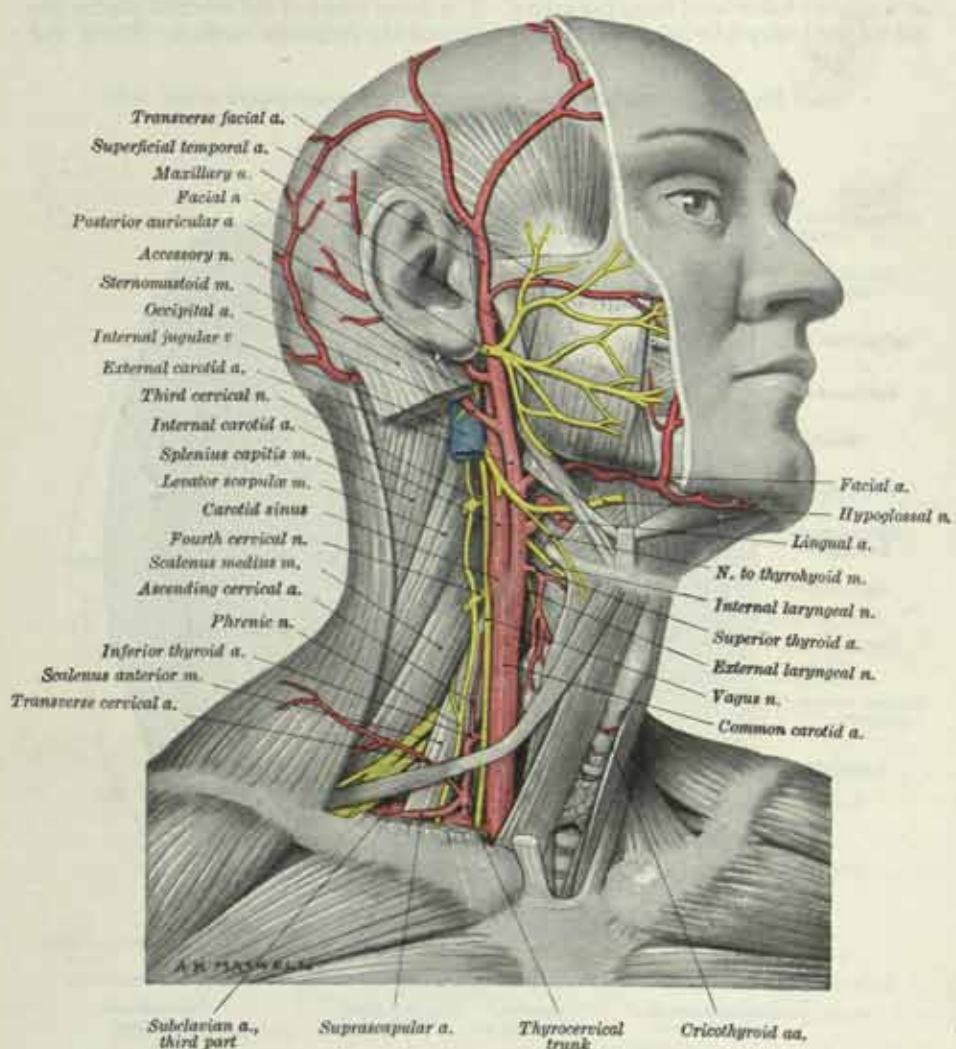
Surface Anatomy.—The subclavian artery can be represented by a broad line, convex upwards, drawn from the sternoclavicular joint to the middle of the lower border of the clavicle (fig. 687). The third part of the vessel can be felt pulsating on deep pressure in the lower and anterior angle of the posterior triangle.

Peculiarities.—The subclavian arteries vary in their origin, their course, and the height to which they rise in the neck.

The right subclavian may arise from the brachiocephalic above or below the level of the sternoclavicular joint. It may arise as a separate trunk from the arch of the aorta, and may then be either its first or last branch. When it is the first branch, it

occupies the ordinary position of the brachiocephalic trunk; and when the last, it arises from the left extremity of the arch, and ascends obliquely towards the right side behind the trachea, œsophagus, and right carotid to the inner border of the first rib, whence it follows its ordinary course. In these cases, the proximal part of the artery represents a persistent part of the right dorsal aorta, and the right fourth aortic arch takes no part in its formation (p. 170) so that the right recurrent laryngeal nerve hooks

FIG. 703.—A dissection of the right side of the neck showing the carotid and subclavian arteries and their branches.



The parotid and submandibular glands have been removed together with the lower part of the internal jugular vein, most of the Sternomastoid muscle, and the upper parts of the Stylohyoid and posterior belly of the Digastric muscle.

round the lateral side of the common carotid which is derived from the artery of the third arch. Sometimes, when it arises as the last branch of the arch of the aorta, the right subclavian artery passes between the trachea and the œsophagus.

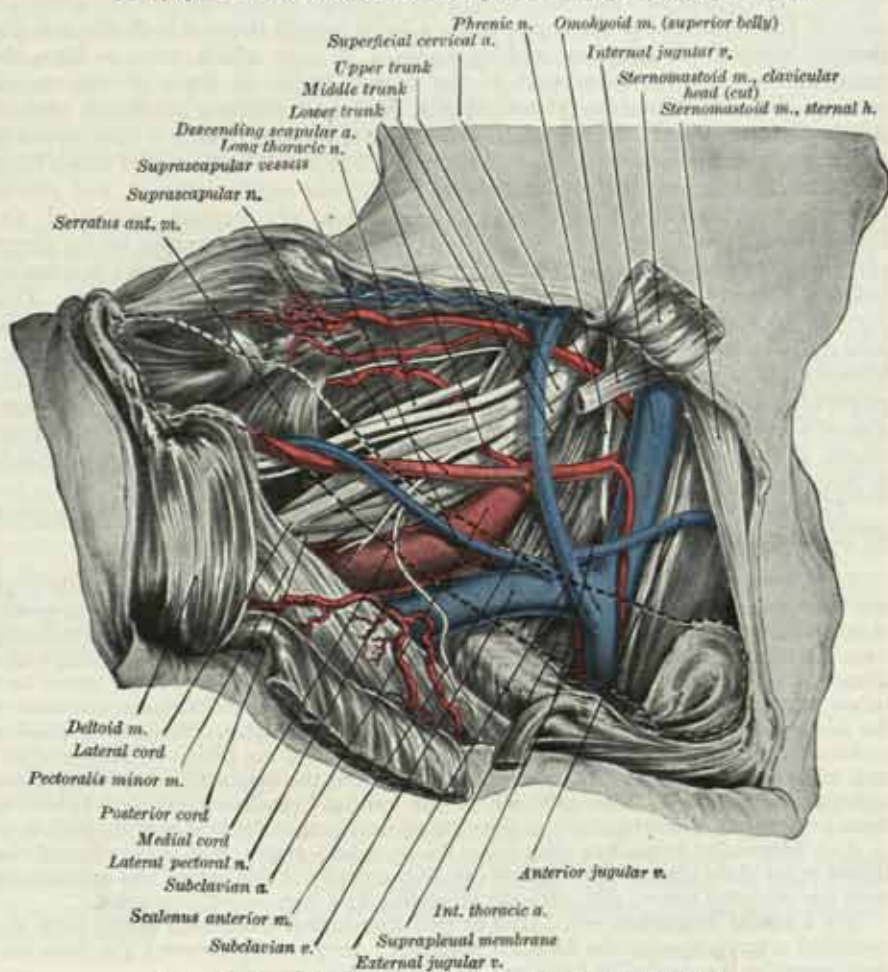
Occasionally the subclavian artery perforates the Scalenus anterior; very rarely it passes in front of that muscle. Sometimes the subclavian vein passes with the artery behind the Scalenus anterior. The artery may ascend as high as 4 cm. above the clavicle or may only reach the level of the upper border of the bone.

The left subclavian is occasionally joined at its origin with the left common carotid. It is more deeply placed than the right subclavian in the first part of its course, and, as a rule, does not reach quite as high a level in the neck.

The posterior border of the Sternomastoid corresponds closely to the lateral border of the Scalenus anterior, so that the third portion of the artery, the part most accessible for operation, lies immediately lateral to the posterior border of the Sternomastoid.

Compression of the subclavian artery may be required to control hæmorrhage, and can be applied effectually in one situation only, viz. where the artery passes across the upper surface of the first rib. In order to compress the vessel in this situation, the shoulder should be depressed and pressure exercised downwards, backwards, and medially in the angle formed by the posterior border of the Sternomastoid with the upper border of the clavicle.

FIG. 704.—The relations of the third part of the right subclavian artery.



N.B.—The clavicle has been removed but is shown as a dotted outline.

Branches.—The branches of the subclavian artery are :

- | | |
|------------------------------|----------------------|
| Vertebral. | Thyrocervical trunk. |
| Internal thoracic (mammary.) | Costocervical trunk. |

On the left side of the neck all four branches generally rise from the first portion of the artery ; on the right side the costocervical trunk usually springs from the second portion. On both sides, the first three branches originate close together at the medial border of the Scalenus anterior.

1. The **vertebral artery** (figs. 685, 694, 700) arises from the upper and posterior part of the first portion of the subclavian artery. It ascends through the foramina in the transverse processes of the upper six cervical vertebræ,* winds behind the lateral

* The vertebral artery sometimes enters the foramen in the transverse process of the fifth vertebra.

mass of the atlas, enters the skull through the foramen magnum, and, at the lower border of the pons, joins the vessel of the opposite side to form the basilar artery.

Relations.—The vertebral artery may be divided into four parts. The *first part* runs upwards and backwards between the Longus colli and the Scalenus anterior and behind the common carotid artery. In front, it is related to the common carotid artery and the vertebral vein, and is crossed by the inferior thyroid artery; on the left side it is crossed also by the thoracic duct. Behind, it is related to the transverse process of the seventh cervical vertebra, the inferior cervical ganglion (fig. 995) and the ventral rami of the seventh and eighth cervical nerves. The *second part* ascends through the foramina transversaria of the upper six cervical vertebrae, and is accompanied by a large branch derived from the inferior cervical sympathetic ganglion, and by a plexus of veins which unite to form the vertebral vein at the lower part of the neck. It lies in front of the ventral rami of the cervical nerves (C.2-C.6) (fig. 685), and pursues an almost vertical course as far as the transverse process of the axis, through which it runs upwards and laterally to the foramen transversarium of the atlas. The *third part* issues from the latter foramen on the medial side of the Rectus capitis lateralis, and curves backwards behind the lateral mass of the atlas, the ventral ramus of the first cervical nerve being on its medial side; it then lies in the groove on the upper surface of the posterior arch of the atlas, and enters the vertebral canal by passing below the lower, arched border of the posterior atlanto-occipital membrane. This part of the artery is covered by the Semispinalis capitis and is contained in the *suboccipital triangle* (fig. 690). The dorsal ramus of the first cervical nerve lies between the artery and the posterior arch of the atlas (fig. 574). The *fourth part* pierces the dura and the arachnoid mater, ascends in front of the roots of the hypoglossal nerve (fig. 827), and inclines medially to the front of the medulla oblongata where, at the lower border of the pons, it unites with the vessel of the opposite side to form the basilar artery (fig. 697).

The branches of the vertebral artery may be divided into two sets—those given off in the neck, and those within the cranium.

(a) **Cervical branches.**—(1.) **Spinal branches** enter the vertebral canal through the intervertebral foramina, and each divides into two branches. Of these, one passes along the roots of the nerves to supply the spinal cord and its membranes, anastomosing with the other arteries of the spinal cord; the other divides into an ascending and a descending branch, which unite with similar branches from the arteries above and below, so that two lateral anastomotic chains are formed on the posterior surfaces of the bodies of the vertebrae, near the attachment of the pedicles. From these anastomotic chains branches are supplied to the periosteum and the bodies of the vertebrae, and others communicate with similar branches from the opposite side; from these communications small twigs arise which join similar branches above and below, to form a central anastomotic chain on the posterior surfaces of the bodies of the vertebrae.

(2.) **Muscular branches** arise from the vertebral artery as it curves round the lateral mass of the atlas. They supply the deep muscles of this region and anastomose with the occipital artery, and with the ascending and deep cervical arteries.

(b) **Cranial branches.**—(1.) One or two **meningeal branches** spring from the vertebral artery opposite the foramen magnum; they ramify between the bone and dura mater in the cerebellar fossa and supply the falx cerebelli.

(2.) The **posterior spinal artery** may arise from the vertebral artery at the side of the medulla oblongata, but is most frequently derived from the posterior inferior cerebellar artery. It passes backwards, and then descends as two branches, one in front of and the other behind the dorsal roots of the spinal nerves; these are reinforced by a succession of spinal twigs which arise from the vertebral, ascending cervical, posterior intercostal and lumbar arteries, and enter the vertebral canal through the intervertebral foramina; by means of these branches the posterior spinal arteries are continued to the lower part of the spinal cord. There is some evidence* that the cervical region of the cord is supplied from above downwards by blood directly from the posterior spinal arteries. At lower levels it appears that the blood flows upwards in the posterior spinal arteries and that the contributions received from the intercostal and lumbar arteries to these portions of the vessels is relatively unimportant. The main source of the blood in the inferior parts seems to be two vessels which pass backwards from the termination of the anterior spinal artery at the level of the fifth sacral nerve-roots. Branches from the posterior spinal arteries form

* Bolton, *J. Neurol. and Psychiatry*, vol. ii (New series), No. 2, April 1939, p. 137.

a free anastomosis with those of the opposite side. Near its origin each posterior spinal artery gives off an ascending branch, which ends at the side of the fourth ventricle.

(3.) The **anterior spinal artery** is a small branch, which arises near the termination of the vertebral artery; it descends in front of the medulla oblongata and unites with its fellow of the opposite side near the level of the lower end of the olive of the medulla oblongata. The single trunk, thus formed, descends on the front of the spinal cord, and is reinforced by a succession of small spinal branches which enter the vertebral canal through the intervertebral foramina; these branches are derived from the vertebral, the ascending cervical, posterior intercostal, and lumbar arteries. They unite, by means of ascending and descending branches, to form a single anterior median artery, which extends as far as the lower part of the spinal cord, and is continued as a slender twig on the filum terminale. This vessel is placed in the pia mater along the anterior median fissure; it supplies that membrane, and the substance of the spinal cord, and sends off branches at its lower part to be distributed to the cauda equina. Branches pass from the anterior spinal arteries, and from the beginning of the trunk formed by their union, to the medulla oblongata, where they are distributed to its central portion, being sharply limited dorsally to the region of the trigonum hypoglossi.*

(4.) The **posterior inferior cerebellar artery** (fig. 697) is the largest branch of the vertebral artery, but is not infrequently absent. It arises near, and winds backwards round, the lower end of the olive of the medulla oblongata; it then ascends behind the roots of the glossopharyngeal and vagus nerves to the lower border of the pons, where it turns downwards along the inferolateral border of the fourth ventricle. Finally, it runs laterally into the vallicula of the cerebellum, where it divides into a medial and a lateral branch. The medial branch runs backwards between the cerebellar hemisphere and the inferior vermis, supplying branches to both; the lateral branch supplies the under surface of the hemisphere, as far as its lateral border, and anastomoses with the anterior inferior cerebellar and superior cerebellar branches of the basilar artery. The trunk of the artery supplies branches to the medulla oblongata and to the choroid plexus of the fourth ventricle, and sends a branch upwards lateral to the tonsil of the cerebellum to supply the dentate nucleus of the cerebellum (Shellshear †). The area supplied in the medulla oblongata lies dorsal to the olivary nucleus and lateral to the nucleus and emerging fila of the hypoglossal nerve, and usually includes the nucleus of the spinal tract of the trigeminal nerve and the spino-thalamic tracts.

(5.) The **medullary arteries** are several minute vessels which spring from the vertebral and its branches, and are distributed to the medulla oblongata.

The **basilar artery** (figs. 697, 700), so named from its position at the base of the skull, is formed by the junction of the two vertebral arteries; it extends from the lower to the upper border of the pons, and is contained within the cisterna pontis. It lies in a shallow, median groove on the ventral surface of the pons. It is placed between the two abducent nerves at the lower border, and between the two oculomotor nerves at the upper border of the pons, where it divides into the two posterior cerebral arteries.

Branches.—The **pontine branches** are a number of small vessels which come off from the front and sides of the basilar artery, and supply the pons and adjacent parts of the brain.‡

The **labyrinthine (internal auditory) artery**, a long slender branch, may arise from the lower part of the basilar artery but is more often derived from the anterior inferior cerebellar artery; it accompanies the facial and the eighth nerves into the internal acoustic meatus, and is distributed to the internal ear.

The **anterior inferior cerebellar artery** (fig. 697) arises from the lower part of the basilar artery. It runs backwards and laterally, usually ventral to the abducent nerve, the facial and eighth nerves, and commonly forms a loop which penetrates for a variable distance into the internal acoustic meatus below the nerves.§ The labyrinthine artery frequently arises from the summit of the loop. On emerging from the meatus the artery is distributed to the anterior and lateral parts of the under

* J. L. Shellshear, *J. Anat.*, **61**, 1927.

† J. L. Shellshear, *Lancet*, May 27th, 1922.

‡ J. S. B. Stopford, *J. Anat.*, **50**, **51**, 1916.

§ Sydney Sunderland, *Brain*, **68**, **1**, 1945.

surface of the cerebellum, where it anastomoses with the posterior inferior cerebellar branch of the vertebral artery. A few branches are supplied by the anterior inferior cerebellar artery to the lower and lateral parts of the pons, and sometimes to the upper part of the medulla oblongata.

The **superior cerebellar artery** (fig. 697) arises near the termination of the basilar. It passes laterally immediately below the oculomotor nerve, which separates it from the posterior cerebral artery, winds round the cerebral peduncle close to and below the trochlear nerve, and, arriving at the superior surface of the cerebellum, divides into branches which ramify in the pia mater, supplying this aspect of the cerebellum and anastomosing with branches of the inferior cerebellar arteries. In addition, branches are given to the pons, the pineal body, the anterior (superior) medullary velum and the tela chorioidea of the third ventricle.

The **posterior cerebral artery** (figs. 697, 698, 699), frequently double, is larger than the superior cerebellar artery, from which it is separated near its origin by the oculomotor nerve, and on the side of the mesencephalon by the trochlear nerve. Passing laterally, parallel with the superior cerebellar artery, and receiving the posterior communicating branch from the internal carotid artery, it winds round the cerebral peduncle, and reaches the tentorial surface of the cerebrum, where it breaks up into branches for the supply of the temporal and occipital lobes.

The branches of the posterior cerebral artery are divided into two sets, central and cortical.

Central branches.—The *posteromedial central branches* (fig. 700) are several small arteries which arise at the commencement of the posterior cerebral artery; these, with similar branches from the posterior communicating, pierce the posterior perforated substance, and supply the anterior part of the thalamus, the lateral wall of the third ventricle and the globus pallidus of the lentiform nucleus. The *posterior choroid branches* are usually three or four in number. One, or more, courses over the lateral geniculate body and helps to supply it, before entering the posterior part of the inferior horn of the lateral ventricle through the lower part of the choroidal fissure. The others curl round the posterior end of the thalamus and pass through the transverse fissure, to enter the tela chorioidea of the third ventricle, and through the upper part of the choroidal fissure; they supply the choroid plexuses of the third and lateral ventricles, and give some twigs to the fornix. The *postero-lateral central branches* are small arteries which arise from the posterior cerebral artery after it has turned round the cerebral peduncle; they supply the cerebral peduncle, the posterior part of the thalamus, and the pineal, quadrigeminal and medial geniculate bodies.

Cortical branches.—The *temporal branches*, usually two in number, are distributed to the uncus, the parahippocampal, the medial and lateral occipito-temporal gyri; the *occipital branches* supply the cuneus, gyrus lingualis and the posterior part of the lateral surface of the occipital lobe; and the *parieto-occipital* supply the cuneus and the precuneus.

2. The **internal thoracic (mammary) artery** (fig. 705) arises about 2 cm. above the sternal end of the clavicle from the inferior surface of the first portion of the subclavian artery, opposite the thyrocervical trunk. It descends behind the cartilages of the upper six ribs at a distance of 1.25 cm. from the lateral border of the sternum, and at the level of the sixth intercostal space divides into the *musculophrenic* and *superior epigastric* arteries.

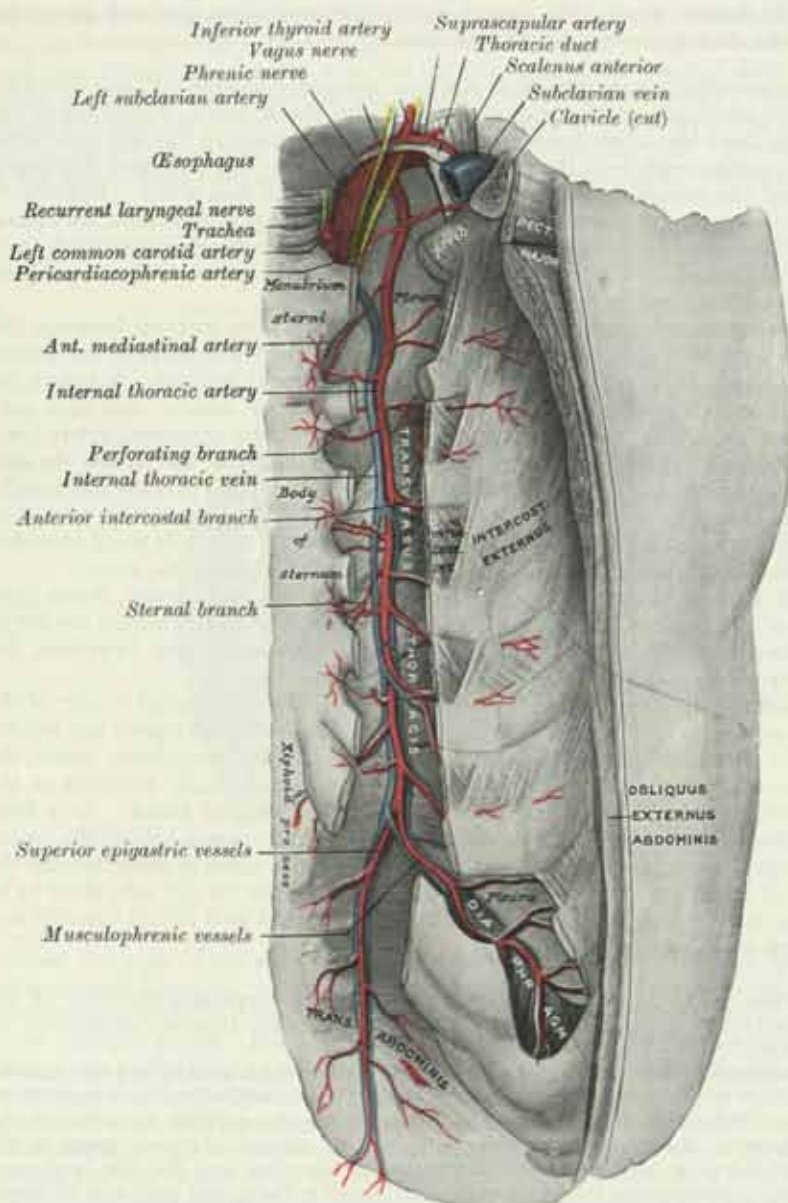
Relations.—It runs at first downwards, forwards, and medially behind the sternal end of the clavicle, the internal jugular and brachiocephalic veins, and the first costal cartilage. As the artery enters the thorax, the phrenic nerve crosses it obliquely from the lateral to the medial side, the nerve usually passing in front of the artery. Below the first costal cartilage it descends almost vertically to its point of bifurcation. It is covered in front by the Pectoralis major, the cartilages of the upper six ribs and the intervening external (anterior) intercostal membranes and Internal intercostals, and is crossed by the terminal portions of the upper six intercostal nerves. It is separated from the pleura, as far as the second or third costal cartilage, by a strong layer of fascia; below this level, by the transversus thoracis. It is accompanied by a chain of lymph nodes and a pair of veins: about the level of the third costal cartilage the veins unite to form a single vessel, which runs medial to the artery and ends in the brachiocephalic vein.

Branches.—The **pericardiophrenic artery** is a long, slender branch which

accompanies the phrenic nerve, between the pleura and pericardium, to the Diaphragm; it gives branches to the pleura, pericardium, and Diaphragm, and anastomoses with the musculophrenic and phrenic arteries.

The **mediastinal arteries** are small vessels, distributed to the areolar tissue and lymph nodes in the anterior mediastinum, and to the remains of the thymus.

FIG. 705.—The left internal thoracic (mammary) artery.



The **pericardial branches** supply the upper part of the anterior surface of the pericardium.

The **sternal branches** are distributed to the Transversus thoracis (Sternocostalis) and to the posterior surface of the sternum.

The anterior mediastinal, pericardial and sternal branches, together with some twigs from the pericardiophrenic, anastomose with branches from the posterior intercostal and bronchial arteries, and form a subpleural mediastinal plexus.

The **anterior intercostal branches** are distributed to the upper six intercostal spaces. Two in each space, they pass laterally, one lying near the lower margin of the

upper rib, and the other near the upper margin of the lower rib, and anastomose with the posterior intercostal arteries. They are at first situated between the pleura and the Internal intercostal muscles, and then between the Intercostales intimi and the Internal intercostals. They supply the Intercostal muscles and send branches through them to the Pectoral muscles and the mamma.

The **perforating branches** emerge through the upper five or six intercostal spaces, with the anterior cutaneous branches of the corresponding intercostal nerves. They pierce the Pectoralis major, and curving laterally, supply that muscle and the skin. In the female, those of the second, third and fourth spaces give branches to the mamma, and during lactation are of large size.

The **musculophrenic artery** is directed obliquely downwards and laterally, behind the cartilages of the seventh, eighth and ninth ribs; it perforates the Diaphragm near the ninth costal cartilage, and ends opposite the last intercostal space. It anastomoses with the phrenic artery, the lower two posterior intercostal arteries and the ascending branch of the deep circumflex iliac artery. It gives off two anterior intercostal branches to each of the seventh, eighth and ninth intercostal spaces; these are distributed in a manner similar to the anterior intercostals from the internal thoracic. The musculophrenic also gives branches to the lower part of the pericardium and to the abdominal muscles.

The **superior epigastric artery** descends through the interval between the costal and xiphoid origins of the Diaphragm, lying on the lower fibres of the Transversus thoracis and the upper fibres of the Transversus abdominis. It enters the sheath of the Rectus abdominis, at first lying behind the muscle, and then perforating and supplying it, and anastomosing with the inferior epigastric artery from the external iliac. Branches perforate the sheath of the Rectus, and supply the skin of the abdomen, and a small branch passes in front of the xiphoid process and anastomoses with the artery of the opposite side. The superior epigastric artery also gives some twigs to the Diaphragm, while from the artery of the right side small branches extend into the falciform ligament and anastomose with the hepatic artery.

3. The **thyrocervical trunk** (figs. 685, 703), a short, wide trunk, arises from the front of the first portion of the subclavian artery, close to the medial border of the Scalenus anterior, and divides almost immediately into three branches, the *inferior thyroid, suprascapular and transverse cervical*.

The **inferior thyroid artery** runs upwards in front of the medial border of the Scalenus anterior; it then turns medially in front of the vertebral vessels and behind the carotid sheath and its contents, and usually behind the sympathetic trunk, the middle cervical ganglion of which rests upon the vessel; it finally descends on the Longus colli to the lower border of the lobe of the thyroid gland. At a little distance from the gland the inferior thyroid artery usually passes behind the recurrent laryngeal nerve, but when the gland is reached the nerve is often behind the branches of the artery or it may pass between them.* On the *left side*, close to its origin, the artery is crossed anteriorly by the thoracic duct as it curves laterally and downwards to its termination (p. 882).

Branches.—The **muscular branches** supply the depressor muscles of the hyoid bone, the Longus colli, Scalenus anterior and Inferior constrictor of the pharynx.

The **ascending cervical artery** is a small branch which arises from the inferior thyroid artery as that vessel turns medially behind the carotid sheath; it ascends on the anterior tubercles of the transverse processes of the cervical vertebrae in the interval between the Scalenus anterior and Longus capitis. It gives twigs to the muscles of the neck, and sends one or two spinal branches into the vertebral canal through the intervertebral foramina to be distributed to the spinal cord and its membranes, and to the bodies of the vertebrae, in the same manner as the spinal branches of the vertebral artery. It anastomoses with branches of the vertebral, ascending pharyngeal, occipital and deep cervical arteries.

The **inferior laryngeal artery** ascends upon the trachea in company with the recurrent laryngeal nerve; it enters the larynx deep to the lower border of the Inferior constrictor muscle, and supplies its muscles and mucous membrane, anastomosing with the artery from the opposite side, and with the superior laryngeal branch of the superior thyroid artery.

The **tracheal branches** are distributed to the trachea and anastomose below with the bronchial arteries.

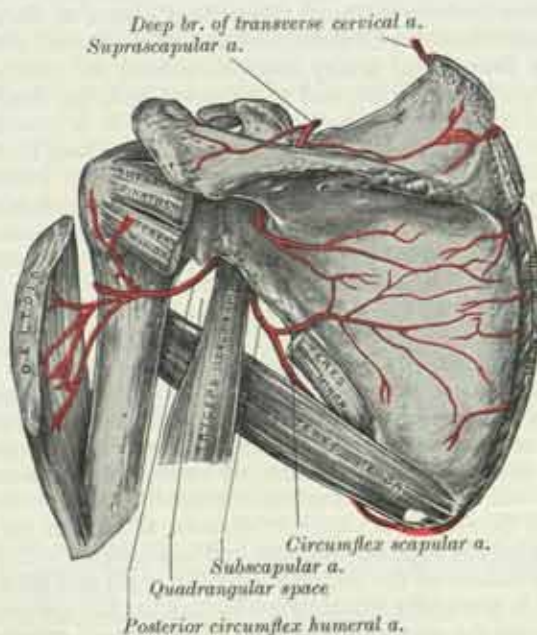
* F. G. Parsons, *J. Anat.*, 54, 1920.

The **œsophageal branches** supply the œsophagus and anastomose with the œsophageal branches of the thoracic aorta.

The **glandular branches** comprise an inferior and an ascending branch ; they are distributed to the posterior and inferior parts of the thyroid gland, and anastomose with the superior thyroid artery and with the opposite inferior thyroid artery ; the ascending branch supplies the superior parathyroid gland.

The **suprascapular artery** (fig. 704) passes at first downwards and laterally across the Scalenus anterior and the phrenic nerve, behind the internal jugular vein and the Sternomastoid ; it then crosses the subclavian artery and the brachial plexus, and runs behind and parallel with the clavicle and Subclavius, and deep to the inferior belly of the Omohyoid, to the superior border of the scapula ; here it passes above (occasionally below) the suprascapular ligament, which separates it from the suprascapular nerve, and enters the supraspinous fossa (fig. 706). In this situation it lies on the bone, and supplies branches to the Supraspinatus. It then descends

FIG. 706.—The scapular anastomosis of the left side ; dorsal aspect.



behind the neck of the scapula, through the great scapular notch and deep to the spinoglenoid ligament, to reach the deep surface of the Infraspinatus, where it anastomoses with the circumflex scapular artery, and the deep branch of the transverse cervical artery. Besides distributing branches to the Sternomastoid, Subclavius, and neighbouring muscles, it gives off a *suprasternal branch*, which crosses over the sternal end of the clavicle to the skin of the upper part of the chest ; and an *acromial branch*, which pierces the Trapezius and supplies the skin over the acromion, anastomosing with the thoraco-acromial (acromiothoracic) artery. As the suprascapular artery passes above the suprascapular ligament, it sends a branch into the subscapular fossa, where it ramifies beneath the Subscapularis, and anastomoses with the subscapular artery and with the deep branch of the transverse cervical artery. The suprascapular artery also sends articular branches to the acromioclavicular and shoulder-joints, and nutrient arteries to the clavicle and scapula. Not infrequently the suprascapular artery arises from the third part of the subclavian artery.

The **transverse cervical artery** (fig. 704) lies at a higher level than the suprascapular artery ; it crosses in front of the phrenic nerve and the Scalenus anterior, and in front of the brachial plexus, and is covered by the internal jugular vein, Sternomastoid and Platysma. It crosses the floor of the posterior triangle of the neck, to reach the anterior margin of the Levator scapulæ, where it divides into a superficial and a deep branch.

The *superficial branch* ascends deep to the anterior part of the Trapezius, distributing branches to it and the neighbouring muscles, and to the lymph nodes in the neck; it anastomoses with the superficial branch of the ramus descendens of the occipital artery.

The *deep branch* (fig. 706) passes under cover of the Levator scapulæ to the superior angle of the scapula, and then descends under cover of the Rhomboids along the medial border of the scapula as far as the inferior angle of the bone. It supplies branches to the Rhomboids, Latissimus dorsi and Trapezius, and anastomoses with the suprascapular and subscapular arteries, and with the posterior branches of some of the posterior intercostal arteries.

Peculiarities.—Frequently the superficial branch arises directly from the thyrocervical trunk and is then termed the *superficial cervical artery*. In this event, the deep branch arises from the third, more rarely from the second, part of the subclavian (fig. 704) and is termed the *descending scapular artery*. It usually passes between the upper and middle trunks of the brachial plexus.

4. The *costocervical trunk* (fig. 701) arises from the back of the second part of the subclavian artery on the right side, but from the first part of the artery on the left side. It arches backwards above the cervical pleura to the neck of the first rib, and divides into the superior intercostal and deep cervical arteries.

The *superior intercostal artery* descends behind the pleura in front of the necks of the first and second ribs, and anastomoses with the third posterior intercostal artery. As it crosses the neck of the first rib it is medial to the ventral ramus of the first thoracic nerve, which it crosses at a lower level (fig. 701), and lateral to the first thoracic ganglion of the sympathetic trunk. In the first intercostal space, it gives off the first posterior intercostal artery, which is distributed in a manner similar to the distribution of the lower posterior intercostals. It then descends to become the second posterior intercostal artery and usually joins with a branch from the third. The second posterior intercostal artery is not constant, but is more commonly found on the right side; when absent, its place is supplied by a branch from the aorta.

The *deep cervical artery* (fig. 694) arises, in most cases, from the costocervical trunk, and is analogous to the posterior branch of a posterior intercostal artery: occasionally it is a separate branch from the subclavian artery. Passing backwards above the eighth cervical nerve and between the transverse process of the seventh cervical vertebra and the neck of the first rib (sometimes between the transverse processes of the sixth and seventh cervical vertebrae) it ascends on the back of the neck, between the Semispinales capitis et cervicis, as high as the second cervical vertebra. It supplies the adjacent muscles, and anastomoses with the deep division of the descending branch of the occipital artery (p. 746) and with branches of the vertebral artery. It gives off a spinal twig which enters the vertebral canal through the foramen between the seventh cervical and first thoracic vertebrae.

THE AXILLA

The *axilla* is a pyramidal space, situated between the upper part of the chest wall and the upper part of the medial side of the upper arm.

The *apex* of the axilla is directed upwards towards the root of the neck, and corresponds to the interval between the outer border of the first rib, the superior border of the scapula and the posterior surface of the clavicle; through it the axillary vessels and nerves enter the space from the neck. The *base*, directed downwards, is broad at the chest but narrow and pointed at the arm; it is formed by the skin and a thick layer of fascia, termed the *axillary fascia*, extending between the lower border of the Pectoralis major in front, and the lower border of the Latissimus dorsi behind. The *anterior wall* is formed by the Pectorales major et minor, the former covering the whole of this wall, the latter only its central part. The space between the upper border of the Pectoralis minor and the clavicle is occupied by the clavipectoral fascia. The *posterior wall* is formed by the Subscapularis above, the Teres major and Latissimus dorsi below. On the *medial side* are the first four ribs with their corresponding Intercostal muscles, and the upper part of the Serratus anterior. On the *lateral side*, where the anterior and posterior walls converge, the space is narrow, and is bounded by the humerus, the Coracobrachialis and the Biceps.

The axilla contains the axillary vessels, the infraclavicular part of the brachial

plexus of nerves, with its branches, the lateral branches of some of the intercostal nerves, and a large number of lymph nodes, together with a quantity of fat and loose areolar tissue. The axillary vessels and the brachial plexus of nerves run from the apex to the base along the lateral wall of the axilla; they are placed nearer to the anterior than to the posterior wall, the axillary vein lying to the thoracic side of the axillary artery and partially concealing it. Owing to the obliquity of the upper ribs, the neurovascular bundle, just after it emerges from beneath the clavicle, crosses the first intercostal space. The relations of the structures comprising the bundle are therefore somewhat different in the upper portion of the axilla from what they are in the lower parts. The thoracic branches of the axillary artery are in contact with the Pectoral muscles, and along the lower margin of the Pectoralis minor the lateral thoracic artery passes to the side of the thorax. The subscapular vessels descend on the posterior wall in contact with the lower margin of the Subscapularis, and the subscapular nerves and the thoracodorsal nerve (to Latissimus dorsi) cross the anterior surface of the muscle with different degrees of obliquity; the circumflex scapular vessels wind round the lateral border of the scapula, and the posterior circumflex humeral vessels and the axillary (circumflex) nerve curve backwards close to the surgical neck of the humerus. No vessel of any importance lies on the medial or thoracic side, the upper part of the space being crossed merely by a few small branches from the superior thoracic artery. The long thoracic nerve (to Serratus anterior) descends on the surface of the muscle which it supplies; and the intercostobrachial nerve perforates the upper and anterior part of this wall, and passes across the axilla to the medial side of the upper arm.

The position and arrangement of the lymph nodes are described on p. 886.

Applied Anatomy.—When suppuration occurs in the axilla, the arrangement of the fasciæ plays a very important part in the direction which the pus takes. As described on p. 616, the clavipectoral fascia, after covering the space between the clavicle and the upper border of the Pectoralis minor, splits to enclose this muscle, and at its lower border is incorporated with the axillary fascia at the anterior fold of the axilla. Suppuration may take place either superficial or deep to this layer of fascia; that is, either between the Pectoral muscles or behind the Pectoralis minor; in the former case, the abscess would point either at the border of the anterior axillary fold, or in the groove between the Deltoid and the Pectoralis major; in the latter, the pus would have a tendency to surround the vessels and nerves, and ascend into the neck, that being the direction in which there is least resistance. Its progress towards the surface is prevented by the axillary fascia; its progress backwards, by the insertion of the Serratus anterior; forwards, by the clavipectoral fascia; medially, by the wall of the thorax; and laterally by the upper limb. The pus in these cases, after extending into the neck, has been known to spread through the superior opening of the thorax into the mediastinum. Instances have been recorded where the pus found its way along the vessels into the upper arm.

When an axillary abscess is opened, the knife should be entered in the floor of the axilla, midway between the anterior and posterior margins and near the thoracic side of the space so as to avoid the lateral thoracic, subscapular, and axillary vessels which are in contact respectively with the anterior, posterior and lateral walls of the axilla.

The relations of the vessels and nerves in the several parts of the axilla are important, for it is the universal procedure to remove the lymph nodes from the axilla in operating for cancer of the breast. When such an operation is performed, it is necessary to proceed with much caution in the direction of the lateral wall and apex of the space, as here the axillary vessels are in danger of being wounded.

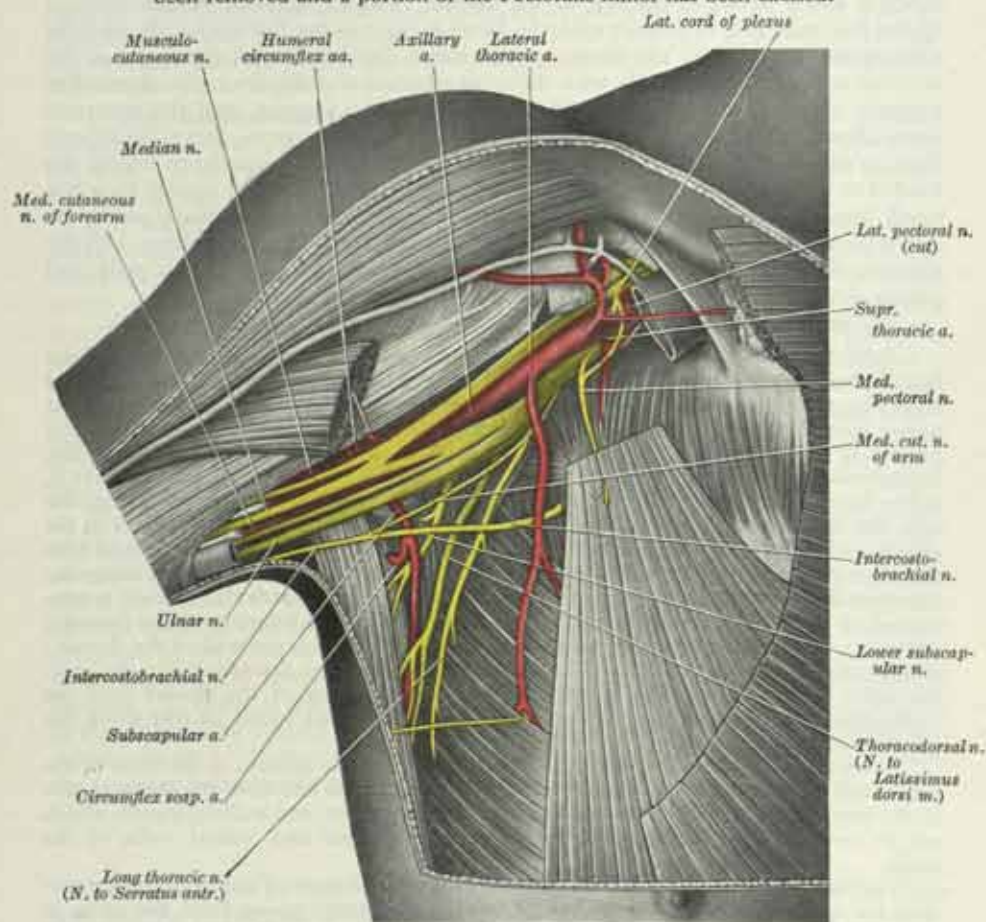
THE AXILLARY ARTERY (fig. 707)

The **axillary artery**, the continuation of the subclavian artery, begins at the outer border of the first rib, and ends at the lower border of the Teres major, beyond which the artery takes the name of brachial. Its direction varies with the position of the limb: thus the vessel is nearly straight when the arm is directed at right angles with the trunk, concave upwards when the arm is elevated above the shoulder, and convex upwards and laterally when the arm lies by the side of the trunk. The first part of the artery is deeply situated, but its terminal part is superficial and is covered only by the skin and fasciæ. The Pectoralis minor crosses the vessel and divides it into three portions; the first part is proximal, the second posterior, and the third distal, to the muscle.

Relations of the first part.—*In front*, the first part of the axillary artery is

covered by the skin, superficial fascia, Platysma, supraclavicular nerves, deep fascia, clavicular fibres of the Pectoralis major and the clavipectoral fascia. This part of the artery is crossed by the lateral pectoral nerve, the loop of communication between it and the medial pectoral nerve, and by the thoraco-acromial and cephalic veins. *Behind*, the artery is related to the first intercostal space and External intercostal muscle, the first and second digitations of the Serratus anterior, the long thoracic nerve and medial pectoral nerve, and the medial cord of the brachial plexus. On the *lateral side* it is related to the lateral and posterior cords of the brachial plexus; on the *medial side*, to the axillary vein, by which it is overlapped.

FIG. 707.—The right axillary artery and its branches. The Pectoralis major has been removed and a portion of the Pectoralis minor has been excised.



The first part of the artery is enclosed, together with the axillary vein and the brachial plexus, in a fibrous sheath, termed the *axillary sheath*, continuous above with the prevertebral layer of the deep cervical fascia.

Relations of the second part.—*In front*, the second part of the axillary artery is related to the skin, superficial and deep fascia, and the Pectoralis major and minor; *behind*, to the posterior cord of the brachial plexus and some areolar tissue, which intervene between it and the Subscapularis; on the *medial side*, to the axillary vein, separated from it by the medial cord of the brachial plexus and the medial pectoral nerve; on the *lateral side*, to the lateral cord of the brachial plexus, which separates it from the Coracobrachialis muscle. The cords of the brachial plexus thus surround the second part of the artery on three sides, and separate it from direct contact with the vein and adjacent muscles.

Relations of the third part.—The third part of the axillary artery extends from the lower border of the Pectoralis minor to the lower border of the Teres major. Its upper part is covered *in front* by the lower part of the Pectoralis major; its lower

part by the skin and fasciæ only. *Behind*, it is related to the lower part of the Subscapularis and the tendons of the Latissimus dorsi and Teres major. On its *lateral side* is the Coracobrachialis, and on its *medial side*, the axillary vein. The nerves of the brachial plexus bear the following relations to this part of the artery; on the *lateral side* are the lateral root and the trunk of the median, and, for a short distance, the musculocutaneous; on the *medial side*, the medial cutaneous nerve of the forearm lies between the axillary artery and vein anteriorly, and the ulnar nerve between the artery and vein posteriorly; the medial cutaneous nerve of the upper arm is on the medial side of the vein; *in front* is the medial root of the median nerve, and *behind*, the radial and axillary nerves, the latter only as far as the lower border of the Subscapularis.

Branches.—1. The **superior thoracic artery** (fig. 707) is a small vessel which arises from the first part of the axillary artery near the lower border of the Subclavius muscle, but it may take origin from the thoraco-acromial artery. Running forwards and medially above the upper border of the Pectoralis minor, it passes between it and the Pectoralis major to the side of the chest. It supplies branches to these muscles, and to the thoracic wall, and anastomoses with the internal thoracic and intercostal arteries.

2. The **thoraco-acromial (acromiothoracic) artery** (fig. 707) is a short trunk which arises from the front of the second part of the axillary artery, its origin being overlapped by the upper edge of the Pectoralis minor. Passing forwards round the upper border of this muscle, it pierces the clavipectoral fascia and divides into four branches—pectoral, acromial, clavicular and deltoid.

The *pectoral branch* descends between the two Pectoral muscles, and is distributed to them and to the breast, anastomosing with the intercostal branches of the internal thoracic artery and with the lateral thoracic artery. The *acromial branch* runs laterally over the coracoid process and under the Deltoid, to which it gives branches; it then pierces that muscle and ends on the acromion, where it anastomoses with the branches of the suprascapular, thoraco-acromial and posterior circumflex humeral arteries. The *clavicular branch* runs upwards and medially between the clavicular part of the Pectoralis major and the clavipectoral fascia; it gives branches to the sternoclavicular joint, and to the Subclavius. The *deltoid branch* often arises with the acromial branch; it crosses over the Pectoralis minor and runs with the cephalic vein in the interval between the Pectoralis major and Deltoid, giving branches to both muscles.

3. The **lateral thoracic artery** (fig. 707) follows the lower border of the Pectoralis minor to the side of the chest, supplies the Serratus anterior and the Pectoral muscles, and sends branches to the axillary lymph nodes, and to the Subscapularis; it anastomoses with the internal thoracic, subscapular, and intercostal arteries, and with the pectoral branch of the thoraco-acromial artery. In the female, the lateral thoracic artery is large, and gives off an *external mammary branch*, which turns round the lower border of the Pectoralis major and supplies the mamma.

4. The **subscapular artery** (fig. 707) is the largest branch of the axillary artery; usually it arises at the lower border of the Subscapularis, which it follows to the inferior angle of the scapula, where it anastomoses with the lateral thoracic and intercostal arteries and with the deep branch of the transverse cervical artery; finally it ends in the neighbouring muscles and adjacent part of the chest-wall. In the lower part of its course it is accompanied by the nerve to the Latissimus dorsi; about 4 cm. from its origin it gives off the *circumflex scapular artery*.

The **circumflex scapular artery** is generally larger than the continuation of the subscapular. It curves round the lateral border of the scapula, traversing the triangular space between the Subscapularis above, the Teres major below, and the long head of the Triceps laterally (fig. 706); it enters the infrapinnous fossa under cover of the Teres minor, and gives off two branches: one (*infrascapular*) enters the subscapular fossa deep to the Subscapularis, which it supplies, and anastomoses with the suprascapular artery and the deep branch of the transverse cervical artery; the other is continued along the lateral border of the scapula, between the Teres major and the Teres minor, and at the dorsal surface of the inferior angle anastomoses with the deep branch of the transverse cervical artery. In addition, small branches are distributed to the posterior part of the Deltoid and the long head of the Triceps, and anastomose with an ascending branch of the arteria profunda brachii.

5. The **anterior circumflex humeral artery** (fig. 707) is a small artery which arises from the lateral side of the axillary artery at the lower border of the Subscapularis. It runs horizontally, behind the Coracobrachialis and short head of the Biceps, in front of the surgical neck of the humerus. On reaching the intertubercular sulcus (bicipital groove), it gives off a branch which ascends in it to supply the head of the humerus and the shoulder-joint. The artery is then continued laterally under cover of the long head of the Biceps and the Deltoid, and anastomoses with the posterior circumflex humeral artery.

6. The **posterior circumflex humeral artery** (fig. 706) is considerably larger than the anterior. It arises from the third part of the axillary artery at the lower border of the Subscapularis, and runs backwards with the axillary nerve through the quadrangular space, which is bounded by the Subscapularis, the capsule of the shoulder-joint and the Teres minor above, the Teres major below, the long head of the Triceps medially, and the surgical neck of the humerus laterally. It winds round the neck of the humerus and distributes branches to the shoulder-joint, the Deltoid, the Teres major and minor, and the long and lateral heads of the Triceps, and gives off a descending branch which anastomoses with the *arteria profunda brachii*. It also anastomoses with the anterior circumflex humeral, suprascapular and thoraco-acromial arteries.

Surface Anatomy.—The axillary artery can be felt pulsating against the lateral wall of the lower part of the axilla. Its upper portion can be mapped out when the arm is raised to a right angle with the trunk, if the point of pulsation indicating the lower portion of the vessel is joined to the midpoint of the lower border of the clavicle.

Peculiarities.—The branches of the axillary artery vary considerably in different subjects. One named *alar thoracic*, and frequently derived from the second part of the artery, is distributed to the fat and the lymph nodes in the axilla. Occasionally the subscapular, circumflex humeral and profunda arteries arise from a common trunk, and when this occurs the branches of the brachial plexus surround this trunk instead of the main vessel. The posterior circumflex humeral artery may arise from the *arteria profunda brachii*; it then passes backwards below the Teres major, instead of accompanying the axillary nerve through the quadrangular space. Sometimes the axillary artery divides into the radial and ulnar arteries, and occasionally it gives origin to the anterior interosseous artery of the forearm.

Applied Anatomy.—Compression of the axillary artery may be required in the removal of tumours, or in amputation of the upper part of the arm. The only situation in which compression can be effectually made is in the lower part of its course: by pressing the artery against the humerus in this situation the circulation may be arrested.

With the exception of the popliteal, the axillary artery is perhaps more frequently lacerated by violent movements than any other artery in the body, particularly in those cases where its coats are diseased. It has occasionally been ruptured in attempts to reduce old dislocations of the shoulder-joint, especially where the artery has become fixed to the capsule of the joint.

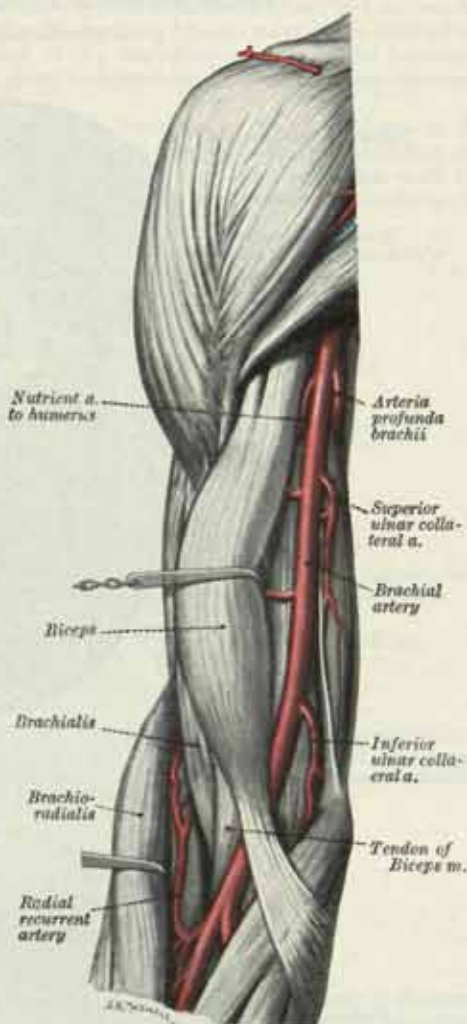
THE BRACHIAL ARTERY (figs. 708, 709, 710)

The **brachial artery** is a continuation of the axillary artery. It begins at the lower border of the tendon of the Teres major, runs down the arm, and ends about 1 cm. below the elbow-joint by dividing into radial and ulnar arteries. At first it lies on the medial side of the humerus, but, largely owing to the inclination of the humerus, it gradually passes to the front of the upper arm and is placed midway between the humeral epicondyles at the elbow. Its pulsations can be felt in the groove medial to the Coracobrachialis and Biceps muscles until it reaches the cubital fossa.

Relations.—The artery is superficial throughout its entire extent, being covered with the skin and the superficial and deep fasciæ; the bicipital aponeurosis lies in front of it opposite the elbow and separates it from the median cubital vein; the median nerve crosses the artery from the lateral to the medial side opposite the insertion of the Coracobrachialis. *Posteriorly* it lies at first on the long head of the Triceps, separated by the radial nerve and the profunda brachii artery. It then lies successively on the medial head of the Triceps, the insertion of the Coracobrachialis, and the Brachialis. *Laterally*, it is in relation above with the median nerve and the Coracobrachialis, below with the Biceps, the two muscles overlapping

the artery to some extent. *Medially*, its upper half is in relation with the medial antebrachial cutaneous and ulnar nerves, its lower half with the median nerve. The basilic vein lies on its medial side, but is separated from it in the lower part of the upper arm by the deep fascia. The artery is closely accompanied by two *venae comitantes*, which are connected at intervals by short transverse branches.

FIG. 708.—The right brachial artery.



THE CUBITAL FOSSA

At the bend of the elbow the brachial artery sinks deeply into a triangular interval which is named the *cubital fossa*. The base of the triangle is represented by a line connecting the two humeral epicondyles; the sides are formed by the medial edge of the Brachioradialis and the lateral margin of the Pronator teres; the floor consists of the Brachialis and Supinator. This fossa contains the tendon of the Biceps, the terminal part of the brachial artery, and its accompanying veins, the origins of the radial and ulnar arteries, and parts of the median and radial nerves. The brachial artery occupies the middle of the fossa, and divides opposite the neck of the radius into the radial and ulnar arteries; it is covered, *in front*, by the skin, the superficial fascia, and the median cubital vein, the last being separated from the artery by the bicipital aponeurosis. *Behind*, the Brachialis separates it from the elbow-joint. The median nerve lies close to the medial side of the artery above, but is separated from its ulnar branch below by the ulnar head of the Pronator teres. The tendon of the Biceps is lateral to the artery; the radial nerve rests upon the Supinator, and is concealed by the Brachioradialis.

The tendon of the Biceps is lateral to the artery; the radial nerve rests upon the Supinator, and is concealed by the Brachioradialis.

Peculiarities.—The brachial artery, accompanied by the median nerve, may leave the medial border of the Biceps, and descend towards the medial epicondyle of the humerus; in such cases it usually passes behind a *supracondylar process* of the humerus, from which a fibrous arch is in most cases thrown over the artery; it then runs behind or through the substance of the Pronator teres, to the bend of the elbow. This variation bears considerable analogy with the normal condition of the artery in some of the carnivora, and has been mentioned in the description of the humerus (p. 371). Occasionally, the upper part of the artery splits into two trunks which reunite. Frequently it divides at a higher level than usual, and the vessels concerned in this high division are three: viz. radial, ulnar and interosseous arteries. Most frequently the radial is given off high up, the other limb of the division consisting of the ulnar and interosseous; in some instances the ulnar originates above the ordinary level, and the radial and interosseous form the other limb of the division; occasionally the interosseous arises high up.

Sometimes long, slender vessels, termed *vasa aberrantia*, connect the brachial or the axillary artery with one or other of the arteries of the forearm. These vessels usually join the radial.

The brachial artery is occasionally concealed in some part of its course, by muscular or tendinous slips derived from the Coracobrachialis, Biceps, Brachialis or Pronator teres.

FIG. 709.—A transverse section through the arm at the junction of the proximal with the intermediate one-third of the humerus.

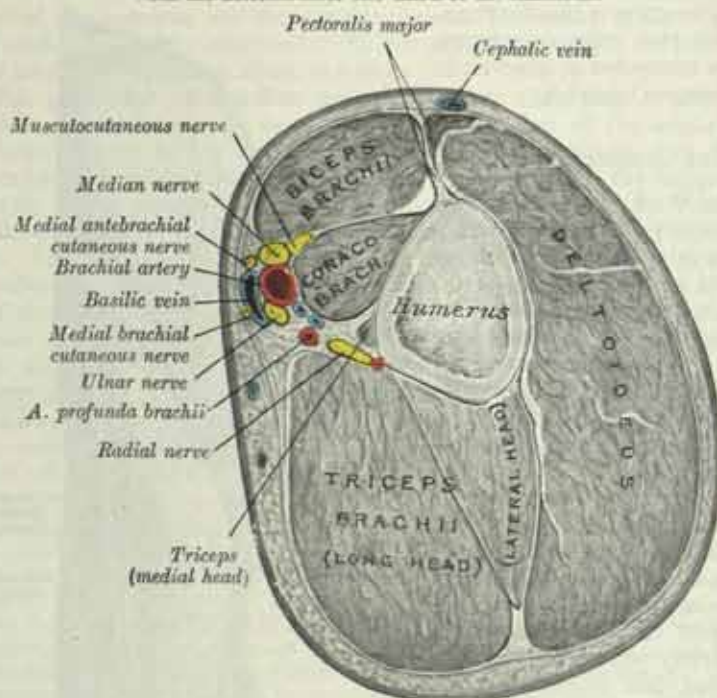
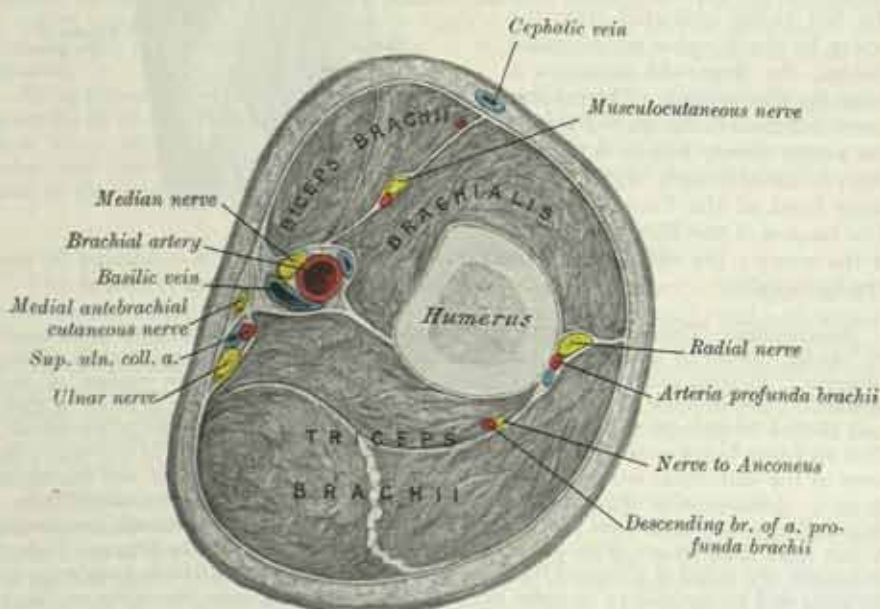


FIG. 710.—A transverse section through the arm, a little below the middle of the shaft of the humerus.

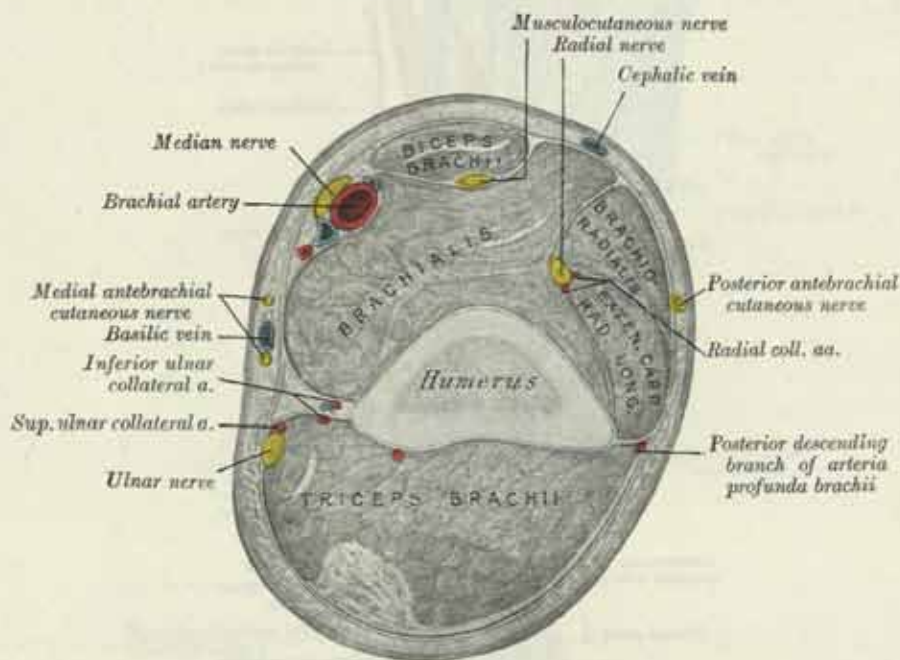


Branches.—1. The **profunda brachii artery** (figs. 708, 709, 712) is a large vessel which arises from the medial and posterior aspect of the brachial artery, just below the lower border of the *Teres major*. It follows the radial nerve closely, running at first

backwards between the long and medial heads of the Triceps, then along the groove for the radial nerve where it is covered by the lateral head of the Triceps. Reaching the lateral side of the arm, it divides into two descending branches (fig. 712). The *radial collateral branch*, which is usually the smaller, pierces the lateral intermuscular septum with the radial nerve, and descends between the Brachioradialis and the Brachialis to the front of the lateral epicondyle of the humerus where it anastomoses with the radial recurrent artery. Another descending branch runs down behind the lateral intermuscular septum to the back of the lateral epicondyle of the humerus, where it anastomoses with the inferior ulnar collateral and the interosseous recurrent arteries.

The profunda brachii artery also supplies (a) branches to the Deltoid and to the three heads of the Triceps, (b) a branch which often springs from the preceding and ascends between the long and lateral heads of the Triceps to anastomose with the posterior circumflex humeral artery, and (c) a collateral twig which descends in the

FIG. 711.—A transverse section through the arm, 2 cm. above the medial epicondyle of the humerus.



medial head of the Triceps with the nerve to the Anconeus, and takes part in the anastomosis above the olecranon. Sometimes the profunda brachii artery supplies a *nutrient artery* to the humerus, which enters the bone behind the deltoid tuberosity.

2. The **nutrient artery** of the humerus arises usually about the middle of the upper arm; it enters the nutrient canal near the insertion of the Coracobrachialis, and is directed downwards.

3. The **superior ulnar collateral artery** (figs. 708, 710, 712) is a small vessel which arises from the brachial a little below the middle of the upper arm; it frequently springs from the upper part of the arteria profunda brachii. It accompanies the ulnar nerve, pierces the medial intermuscular septum, descends between the medial epicondyle and the olecranon, and ends under cover of the Flexor carpi ulnaris by anastomosing with the posterior ulnar recurrent and inferior collateral arteries. It sometimes sends a branch in front of the medial epicondyle, to anastomose with the anterior ulnar recurrent artery.

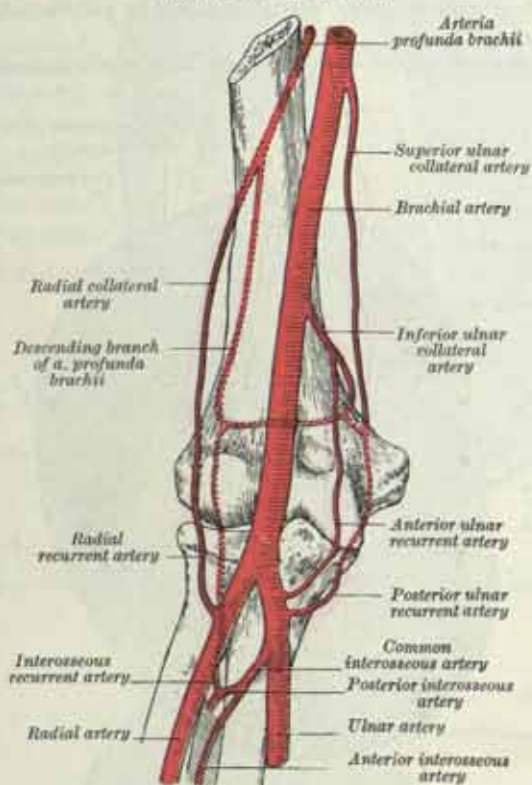
4. The **inferior ulnar collateral (supratrochlear) artery** (figs. 708, 712, 713) arises about 5 cm. above the elbow. It passes medially behind the median nerve upon the Brachialis and, piercing the medial intermuscular septum, winds round the back of the humerus between the Triceps and the bone, forming, by its junction with the posterior descending branch of the arteria profunda brachii, an arch above the olecranon fossa. As the vessel lies on the Brachialis, it gives off branches which descend in front of the medial epicondyle, to anastomose with the anterior ulnar recurrent artery. Behind the medial epicondyle a branch anastomoses with the superior ulnar collateral and posterior ulnar recurrent arteries.

5. The **muscular branches**, three or four in number, are distributed to the Coracobrachialis, Biceps and Brachialis.

Applied Anatomy.—In spite of the fact that the brachial artery is very superficial and but little protected by surrounding parts, it is seldom wounded. This, no doubt, is due to its situation on the medial side of the upper arm, which is little exposed to injury.

Compression of the brachial artery is required in case of amputation and some other operations in the upper arm and forearm, and may be effected in almost any

FIG. 712.—A diagram of the arterial anastomosis around the elbow-joint.



part of the course of the artery. If pressure be made in the upper part of the upper arm, it should be directed laterally; if in the lower part, backwards, as the artery lies on the medial side of the humerus above, and in front of it below. The most favourable situation is about the middle of the arm, where the artery lies on the tendon of the Coracobrachialis on the medial surface of the humerus.

THE RADIAL ARTERY (figs. 713, 714, 715)

The **radial artery**, though smaller than the ulnar artery, appears from its course, to be the more direct continuation of the brachial trunk. It begins at the division of the brachial, about 1 cm. below the bend of the elbow, and passes along the radial side of the forearm to the wrist, where its pulsation can readily be felt in the interval between the Flexor carpi radialis tendon medially and the salient lower part of the anterior border of the radius laterally. It then winds backwards, round the lateral side of the carpus, under cover of the tendons of the Abductor pollicis longus and Extensores pollicis brevis et longus, to the proximal end of the space between the first and second metacarpal bones, where it passes medially between the two heads of the first Dorsal interosseous muscle, into the palm of the hand; it crosses towards the ulnar side of the palm, and forms the

deep palmar arch by uniting with the deep branch of the ulnar artery. The radial artery is therefore divisible into three portions, one in the forearm, a second at the wrist, and a third in the hand.

Relations.—(a) *In the forearm* (figs. 713, 714, 715), the radial artery extends from the neck of the radius to the front part of its styloid process, being placed to the medial side of the shaft of the bone above, and in front of it below. Its upper part

FIG. 713.—The right radial and ulnar arteries. Superficial dissection.



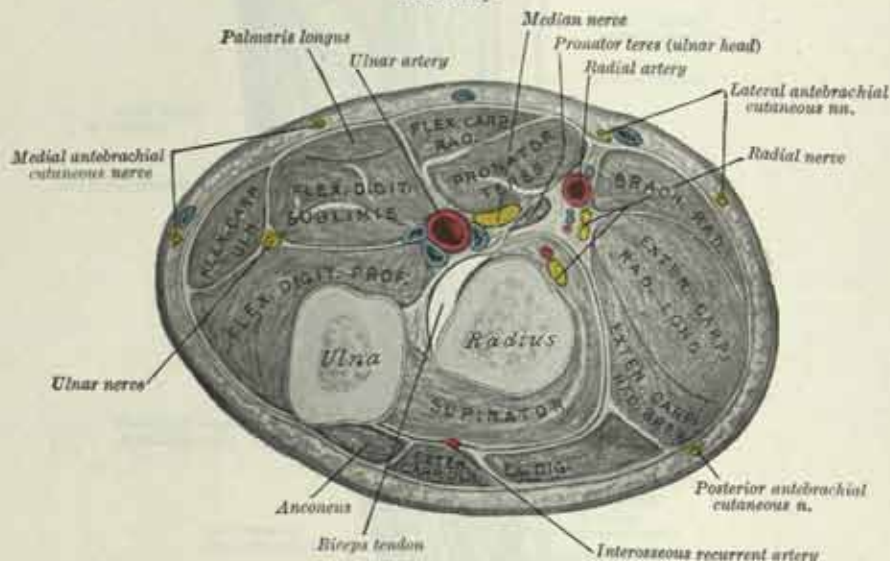
is overlapped by the fleshy belly of the Brachioradialis; the rest of the artery is covered only with the skin, and the superficial and deep fasciæ. It lies successively upon the tendon of the Biceps, the Supinator, the insertion of the Pronator teres, the radial origin of the Flexor digitorum superficialis, the Flexor pollicis longus, the Pronator quadratus and the lower end of the radius. The Pronator teres is medial, and the Brachioradialis lateral, to the upper one-third of the artery; the tendon of the Flexor carpi radialis is medial, and the tendon of the Brachioradialis lateral to its lower two-thirds. The radial nerve (superficial branch) is close to the lateral side of the middle one-third of the vessel; and some filaments of the lateral cutaneous nerve of the forearm run along the lower part of the artery as it winds round the wrist. Throughout its course the vessel is accompanied by a pair of venæ

comitantes. The portion of the radial artery which lies in front of the lower end of the radius and on the lateral side of the tendon of the Flexor carpi radialis is used clinically for observations on the pulse.

(b) *At the wrist* (figs. 716, 718), the radial artery reaches the dorsal aspect of the carpus by passing between the lateral ligament of the wrist and the tendons of the Abductor pollicis longus and Extensor pollicis brevis. It then crosses the scaphoid bone and the trapezium, where its pulsations can readily be detected, and before disappearing between the heads of the first Dorsal interosseous muscle it is crossed by the tendon of the Extensor pollicis longus. In the interval between the two Extensores pollicis it is crossed by the origin of the cephalic vein, and by the digital branches of the radial nerve which go to the thumb and index finger.

(c) *In the hand* (fig. 715), the radial artery, having passed through the proximal end of the first interosseous space, between the heads of the first Dorsal interosseous muscle, runs transversely across the palm; it lies at first deep to the oblique head of

FIG. 714.—A transverse section through the forearm at the level of the radial tuberosity.



the Adductor pollicis, then runs between the oblique and transverse heads, or through the transverse head, of that muscle. At the base of the fifth metacarpal bone it anastomoses with the deep branch from the ulnar artery, and so completes the *deep palmar arch* (fig. 715).

Peculiarities.—In about 12 per cent. of subjects the origin of the radial artery is higher than usual; it then arises more often from the axillary or upper part of the brachial artery than from the lower part of the latter vessel. In the forearm it sometimes lies on the deep fascia instead of beneath it; in turning round the wrist, it occasionally lies on, instead of deep to, the extensor tendons of the thumb.

Branches.—The **radial recurrent artery** (figs. 712, 715) arises immediately below the elbow. It passes between the radial nerve and its posterior interosseous branch and, ascends under cover of the Brachioradialis, lying on the Supinator and Brachialis; it supplies these muscles and the elbow-joint, and anastomoses with the descending branch of the arteria profunda brachii.

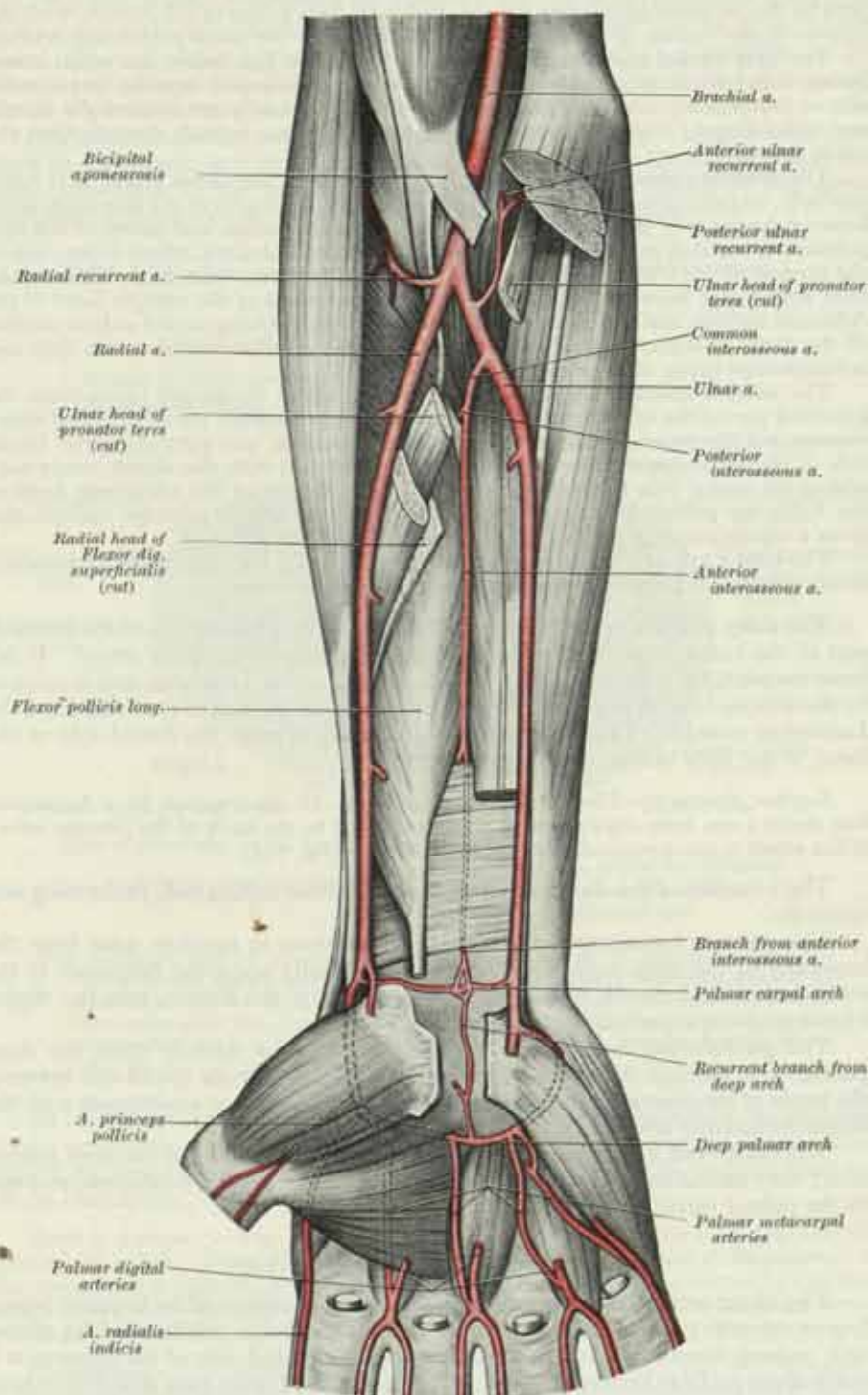
The **muscular branches** are distributed to the muscles on the radial side of the forearm.

The **palmar carpal branch** (fig. 715) is a small vessel which arises near the lower border of the Pronator quadratus, and, running medially across the palmar surface of the carpus, anastomoses under cover of the flexor tendons with the palmar carpal branch of the ulnar artery. This anastomosis is joined by a branch from the anterior interosseous artery, and by recurrent branches from the deep palmar arch, thus forming a *palmar carpal arch*, which supplies the articulations of the wrist and carpus.

The **superficial palmar branch** (fig. 719) arises from the radial artery where this vessel is about to wind round the lateral side of the wrist. It passes through, occasion-

ally over, the muscles of the ball of the thumb, which it supplies, and sometimes anastomoses with the terminal portion of the ulnar artery, completing the superficial palmar arch.

FIG. 715.—The arteries of the right forearm and hand. Deep dissection.



The dorsal carpal branch (fig. 718) is a small vessel which arises deep to the extensor tendons of the thumb, and, running medially across the dorsal surface of the carpus under cover of the extensor tendons, anastomoses with the dorsal carpal

branch of the ulnar artery, and with the anterior and posterior interosseous arteries, to form a *dorsal carpal arch*. Arising from this arch, three slender *dorsal metacarpal arteries* descend on the second, third and fourth Dorsal interosseous muscles and bifurcate into dorsal digital branches for the supply of the adjacent sides of the index, middle, ring and little fingers; they anastomose with the palmar digital branches of the superficial palmar arch; near their origins they anastomose with the deep palmar arch by the *proximal perforating arteries*, and, near their points of bifurcation, with the palmar digital vessels of the superficial palmar arch by the *distal perforating arteries*.

The **first dorsal metacarpal artery** (fig. 718) arises just before the radial artery passes between the two heads of the first Dorsal interosseous muscle, and divides almost immediately into two branches, which supply the adjacent sides of the thumb and index finger; the radial side of the thumb receives a branch directly from the radial artery.

The **arteria princeps pollicis** (fig. 715) arises from the radial artery as it turns medially, on gaining the palm; it descends on the palmar aspect of the first metacarpal bone under cover of the oblique head of the Adductor pollicis and lateral to the first palmar interosseous muscle. At the base of the proximal phalanx, where it lies deep to the tendon of the Flexor pollicis longus, it divides into two branches. These make their appearance between the medial and lateral insertions of the oblique head of the Adductor pollicis, and run along the sides of the thumb, forming, on the palmar surface of the distal phalanx, an arch from which branches are distributed to the skin and subcutaneous tissue of the thumb.

The **arteria radialis indicis** (figs. 715, 719), which frequently arises from the proximal part of the arteria princeps pollicis, descends between the first Dorsal interosseous and the transverse head of the Adductor pollicis, and runs along the lateral side of the index finger to its extremity: it anastomoses with the digital artery supplying the medial side of the finger. At the distal border of the transverse head of the Adductor pollicis this vessel anastomoses with the arteria princeps pollicis, and gives a communicating branch to the superficial palmar arch.

The arteria princeps pollicis and arteria radialis indicis may spring from a common trunk, which is often named the *first palmar metacarpal artery*.

The **deep palmar arch** (fig. 715) is formed by the anastomosis of the terminal part of the radial artery with the deep palmar branch of the ulnar artery. It lies upon the proximal ends of the metacarpal bones and on the Interossei, and is covered by the oblique head of the Adductor pollicis, the flexor tendons of the fingers and the Lumbrical muscles. In its concavity, but running towards the lateral side of the hand, is the deep branch of the ulnar nerve.

Surface Anatomy.—The deep palmar arch can be represented by a horizontal line about 4 cm. long drawn from a point just distal to the hook of the hamate bone; it lies about 1 cm. proximal to the superficial arch (fig. 720).

The branches of the deep palmar arch are: palmar metacarpal, perforating and recurrent.

The **palmar metacarpal arteries** (fig. 715), three in number, arise from the convexity of the deep palmar arch; they run distally upon the Interossei of the second, third and fourth spaces, and, at the clefts of the fingers, join the digital branches of the superficial palmar arch.

The **perforating branches**, three in number, pass dorsally from the deep palmar arch, through the second, third and fourth interosseous spaces and between the heads of the corresponding Dorsal interosseous muscles, to anastomose with the dorsal metacarpal arteries.

The **recurrent branches** (fig. 715) arise from the concavity of the deep palmar arch; they ascend in front of the wrist, supply the intercarpal articulations, and end in the palmar carpal arch.

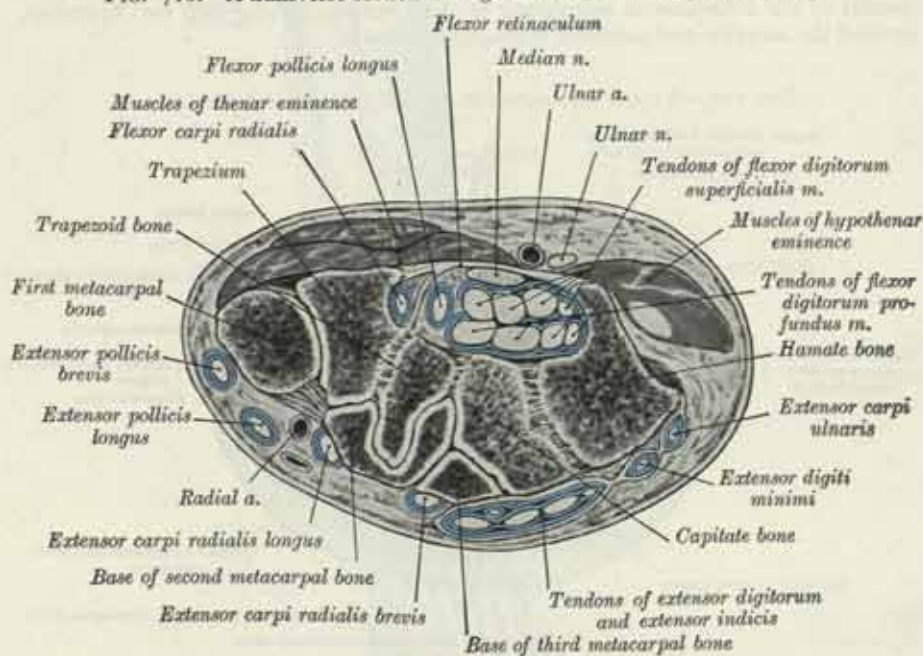
THE ULNAR ARTERY (figs. 713-719)

The **ulnar artery**, the larger of the two terminal branches of the brachial artery, begins opposite to the neck of the radius, about 1 cm. below the bend of the elbow, and, passing downwards and medially, reaches the medial side of the forearm at a point about midway between the elbow and the wrist. It then runs along the medial side of the forearm to the wrist, and crosses the flexor retinaculum on the lateral side of the ulnar nerve, and the pisiform bone. Immediately beyond this bone it gives off a deep branch, and is then continued across the palm under the name of the superficial palmar arch.

Relations.—(a) *In the forearm.*—The upper half of the vessel (figs. 713, 714, 715) is deeply seated, passing obliquely under cover of the Pronator teres, Flexor carpi radialis, Palmaris longus and Flexor digitorum superficialis to the medial side of the forearm, where it is overlapped by the Flexor carpi ulnaris; it lies upon the Brachialis and the Flexor digitorum profundus. Below the elbow the median nerve is on the medial side of the artery for about 2.5 cm. and then crosses the vessel, but is separated from it by the ulnar head of the Pronator teres. The lower half of the vessel (figs. 713, 719) lies upon the Flexor digitorum profundus; it is covered by the skin, superficial and deep fasciæ, and is placed between the Flexor carpi ulnaris and Flexor digitorum superficialis.

It is accompanied by two venæ comitantes, and is overlapped in its middle one-third by the Flexor carpi ulnaris; the ulnar nerve lies close to the medial side of the lower two-thirds of the artery, and the palmar cutaneous branch of this nerve descends on the lower part of the vessel to the palm of the hand.

FIG. 716.—A transverse section through the left wrist. Superior aspect.



The section is slightly oblique and divides the distal row of the carpus, and the bases of the first, second and third metacarpal bones. The arrangement of the tendons of the flexors of the fingers shown in the figure is not diagrammatic but represents the actual condition at this level. Observe that the carpometacarpal joint of the thumb is shut off from the joint between the trapezium and the base of the second metacarpal bone.

(b) *At the wrist* (figs. 715, 716, 719) the ulnar artery is covered by the skin and fasciæ and the Palmaris brevis muscle, and lies between the superficial and the main part of the flexor retinaculum (p. 641). The ulnar nerve and the pisiform bone are on its medial side.

Surface Anatomy.—The vessel commences in the middle of the limb opposite the neck of the radius. From this point the upper part passes to a point at the junction of the upper and middle thirds of a line drawn from the base of the medial epicondyle of the humerus to the lateral edge of the pisiform bone; this line overlies the lower two-thirds of the ulnar artery.

Peculiarities.—The ulnar artery varies in its origin in about 8 per cent. of cases; it frequently arises above the elbow, the brachial being more often the source of origin than the axillary. When its origin is normal, the course of the vessel is rarely changed. When the artery arises high up, it is usually superficial to the flexor muscles in the forearm, lying commonly beneath the fascia, more rarely between the fascia and skin; the brachial artery then gives off the common interosseous artery, and the

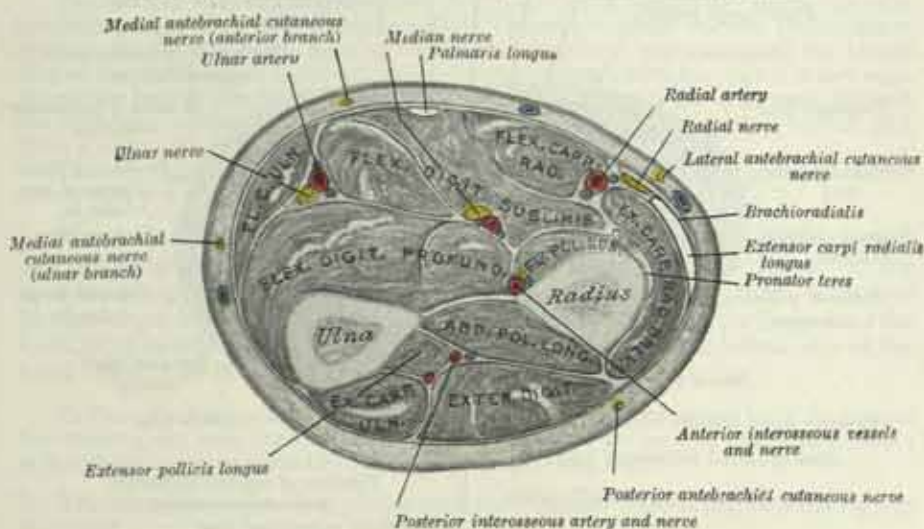
latter, the anterior and posterior ulnar recurrent arteries. Occasionally it is subcutaneous in the upper part of the forearm, and subfascial in the lower part.

Branches.—The **anterior ulnar recurrent artery** (figs. 712, 720), a small branch, arises immediately below the elbow-joint, runs upwards between the Brachialis and Pronator teres, supplies twigs to those muscles, and, in front of the medial epicondyle, anastomoses with the ulnar collateral arteries.

The **posterior ulnar recurrent artery** (figs. 712, 720) is much larger, and arises somewhat lower than the anterior artery. It passes backwards and medially on the Flexor digitorum profundus, behind the Flexor digitorum superficialis, and ascends behind the medial epicondyle of the humerus. In the interval between this process and the olecranon, it lies deep to the Flexor carpi ulnaris, and ascends between the two heads of this muscle, in contact with the ulnar nerve; it supplies the neighbouring muscles and the elbow-joint, and anastomoses with the ulnar collateral, and the interosseous recurrent arteries (fig. 712).

The **common interosseous artery** (fig. 715), about 1 cm. in length, arises immediately below the tuberosity of the radius, and, passing backwards to the upper border of the interosseous membrane of the forearm, divides into two branches, termed the **anterior** and **posterior interosseous arteries**.

FIG. 717.—A transverse section through the middle of the forearm.

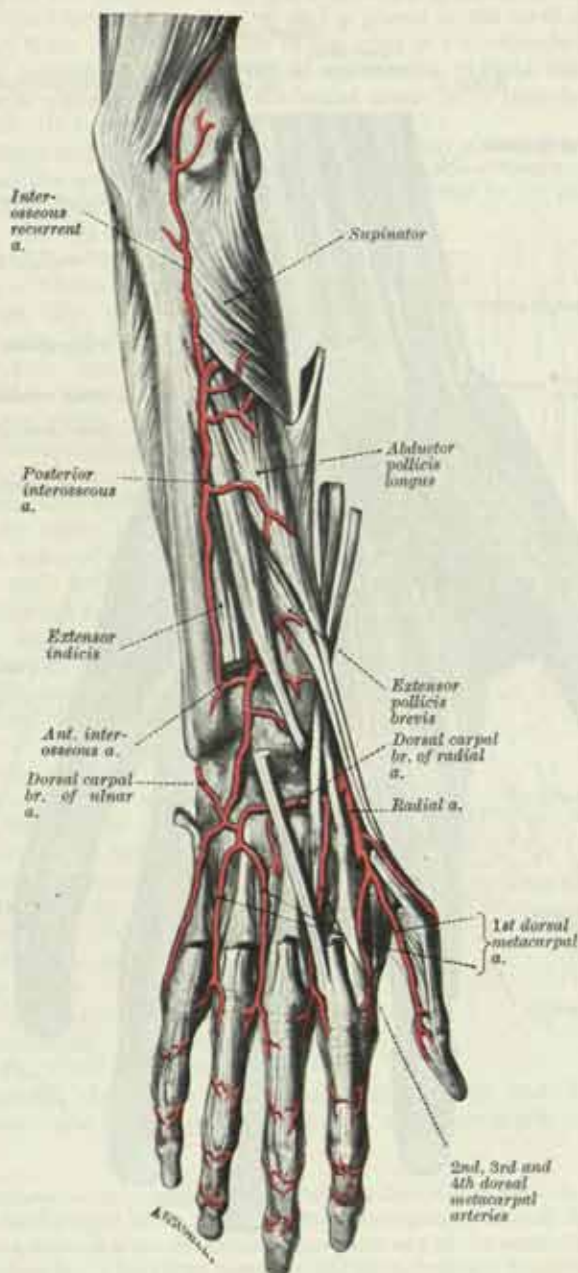


The **anterior interosseous artery** (figs. 715, 718) descends on the anterior surface of the interosseous membrane of the forearm, accompanied by the anterior interosseous branch of the median nerve, and overlapped by the contiguous margins of the Flexor digitorum profundus and Flexor pollicis longus; it gives off *muscular* branches, and the *nutrient* arteries of the radius and ulna. At the upper border of the Pronator quadratus it pierces the interosseous membrane and reaches the back of the forearm, where it anastomoses with the posterior interosseous artery and descends on the back of the wrist in the compartment of the extensor retinaculum containing the tendons of the Extensor digitorum and Extensor indicis, and joins the dorsal carpal arch. Before the artery pierces the interosseous membrane, it sends a branch downwards behind the Pronator quadratus to join the anterior carpal arch. The *arteria mediana*, a long, slender branch, arises from the beginning of the anterior interosseous artery, and accompanies the median nerve closely. Sometimes it is much enlarged and runs with the nerve into the palm of the hand (p. 172), where it may join the superficial palmar arch or end as one or two of the palmar digital arteries.

The **posterior interosseous artery** (figs. 715, 718), usually smaller than the anterior interosseous artery, passes backwards between the oblique cord and the upper border of the antebrachial interosseous membrane. It appears on the back of the forearm between the contiguous borders of the Supinator and the Abductor pollicis longus, and descends between the superficial and deep layers of muscles, to both of which it distributes branches. As it lies upon the Abductor pollicis longus,

it is accompanied by the posterior interosseous nerve. At the lower part of the forearm it anastomoses with the termination of the anterior interosseous artery, and with the dorsal carpal arch. It gives off, near its origin, the *interosseous recurrent artery*, which ascends to the interval between the lateral epicondyle and olecranon,

FIG. 718.—The arteries of the posterior surface of the right forearm and hand.

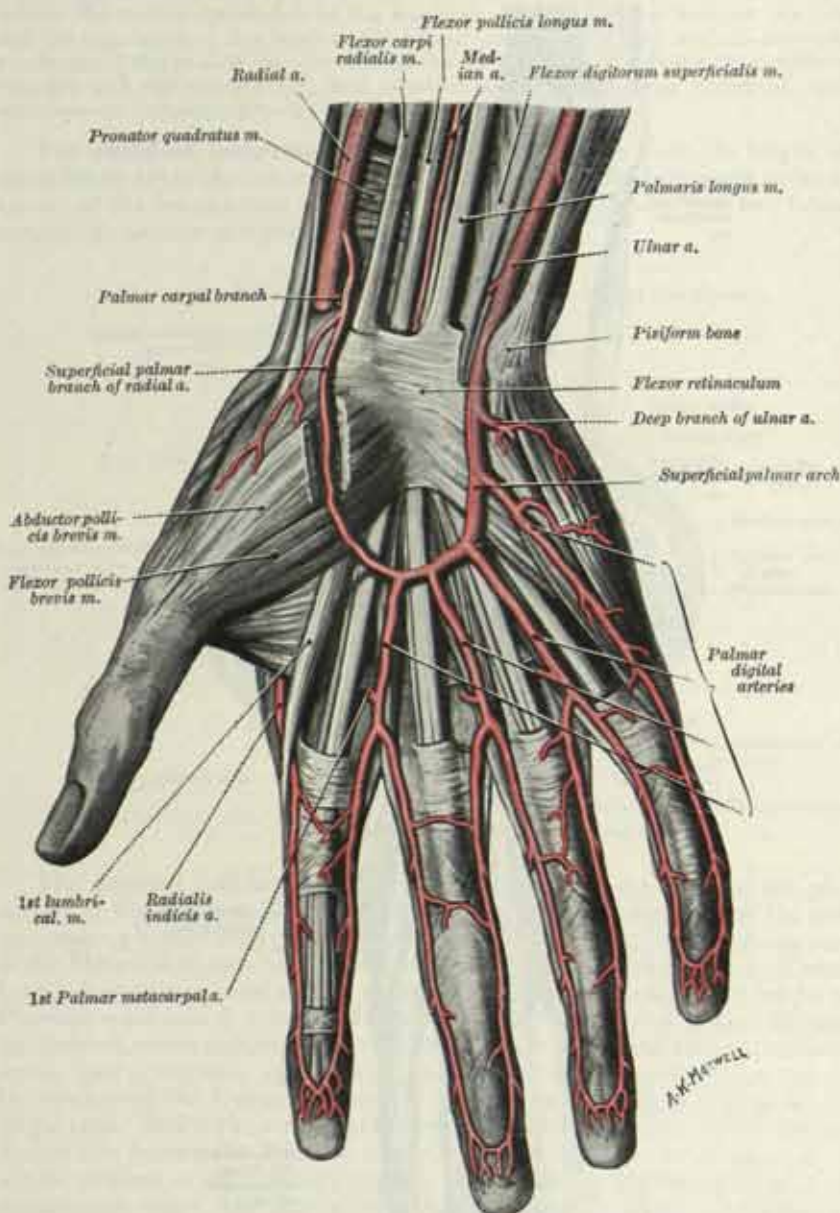


on or through the fibres of the Supinator, but deep to the Anconeus, and anastomoses with the posterior descending branch of the arteria profunda brachii, and with the posterior ulnar recurrent and the ulnar collateral arteries.

The **muscular branches** of the ulnar artery are distributed to the muscles along the ulnar side of the forearm.

The **palmar carpal branch** (fig. 715) is a small vessel which crosses the front of the carpus behind the tendons of the *Flexor digitorum profundus*; it anastomoses with the palmar carpal branch of the radial artery, and assists in forming the palmar carpal arch (p. 784).

FIG. 719.—The superficial palmar arch and its branches. A part of the *Abductor pollicis brevis* muscle has been excised in order to expose completely the superficial palmar branch of the radial artery.



The **dorsal carpal branch** (fig. 718) arises immediately above the pisiform bone, and winds backwards deep to the tendon of the *Flexor carpi ulnaris*; it passes laterally across the dorsal surface of the carpus under cover of the extensor tendons, anastomoses with the dorsal carpal branch of the radial artery, and assists in forming the dorsal carpal arch (p. 785). Near to its origin it gives off a small branch which runs along the ulnar side of the fifth metacarpal bone, and supplies the ulnar side of the dorsal surface of the little finger.

The **deep branch** (figs. 715, 719) passes between the Abductor digiti minimi and Flexor digiti minimi, and through or deep to the origin of the Opponens digiti minimi; it anastomoses with the radial artery, and completes the deep palmar arch; it is accompanied by the deep branch of the ulnar nerve.

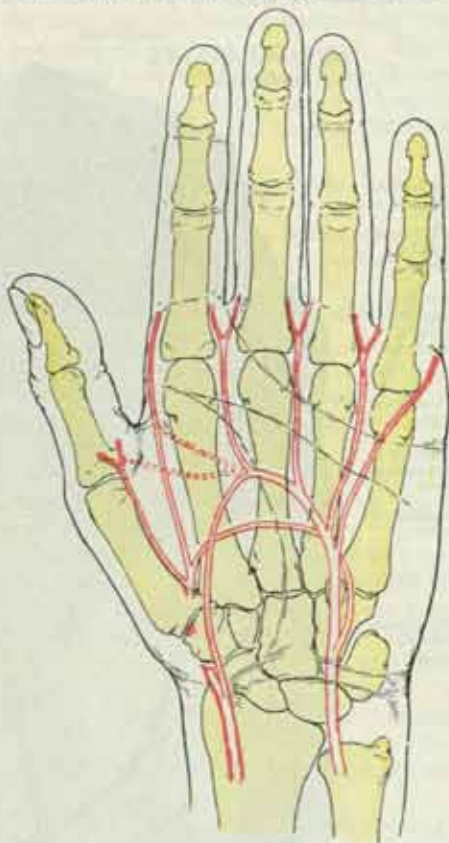
The **superficial palmar arch** (fig. 719) is formed mainly by the ulnar artery, which enters the hand with the ulnar nerve in front of the flexor retinaculum, and on the lateral side of the pisiform bone. It then crosses the hook of the hamate and passes across the palm, forming the superficial palmar arch, the convexity of which is directed towards the fingers, and is placed at the level of a line drawn across the hand from the distal border of the root of the extended thumb. The arch is usually completed by a branch of the arteria radialis indicis, but often by the superficial palmar branch of the radial artery or a branch of the arteria princeps pollicis. It is covered by the palmaris brevis and the palmar aponeurosis, and lies on the Flexor digiti minimi, the branches of the median nerve, the flexor tendons and the Lumbricals.

Branches.—Three **palmar digital arteries** (fig. 719) arise from the convexity of the superficial palmar arch and proceed distally on the second, third and fourth Lumbricals. Each is joined by the corresponding palmar metacarpal artery from the deep palmar arch, and then divides into a pair of vessels, which run along the contiguous sides of the index, middle, ring and little fingers, dorsal to the corresponding digital nerves; they anastomose freely in the subcutaneous tissue of the finger tips and by smaller branches near the interphalangeal joints. Each gives off two dorsal branches, which anastomose with the dorsal digital arteries, and supply the soft parts on the back of the middle and distal phalanges, including the matrix of the finger-nail. The **palmar digital artery** for the medial side of the little finger springs from the arch under cover of the Palmaris brevis.

A free anastomosis takes place between the radial and ulnar arteries, (a) on the front and back of the wrist through the palmar and dorsal carpal arches, and (b) in the hand through the superficial and deep palmar arches, and their digital and metacarpal branches.

Applied Anatomy.—In wounds of the palmar arches it is useless to ligature one of the arteries of the forearm alone, and simultaneous ligature of both radial and ulnar arteries above the wrist is often unsuccessful, on account of the anastomosis carried on by the carpal networks. Therefore, upon the failure of pressure to arrest hæmorrhage, it is expedient, if the ends of the bleeding vessel cannot readily be exposed and tied, to apply a ligature to the brachial artery.

FIG. 720.—The palm of the left hand, showing the positions of the skin creases and the bones, and the surface markings for the palmar arches.



THE ARTERIES OF THE TRUNK

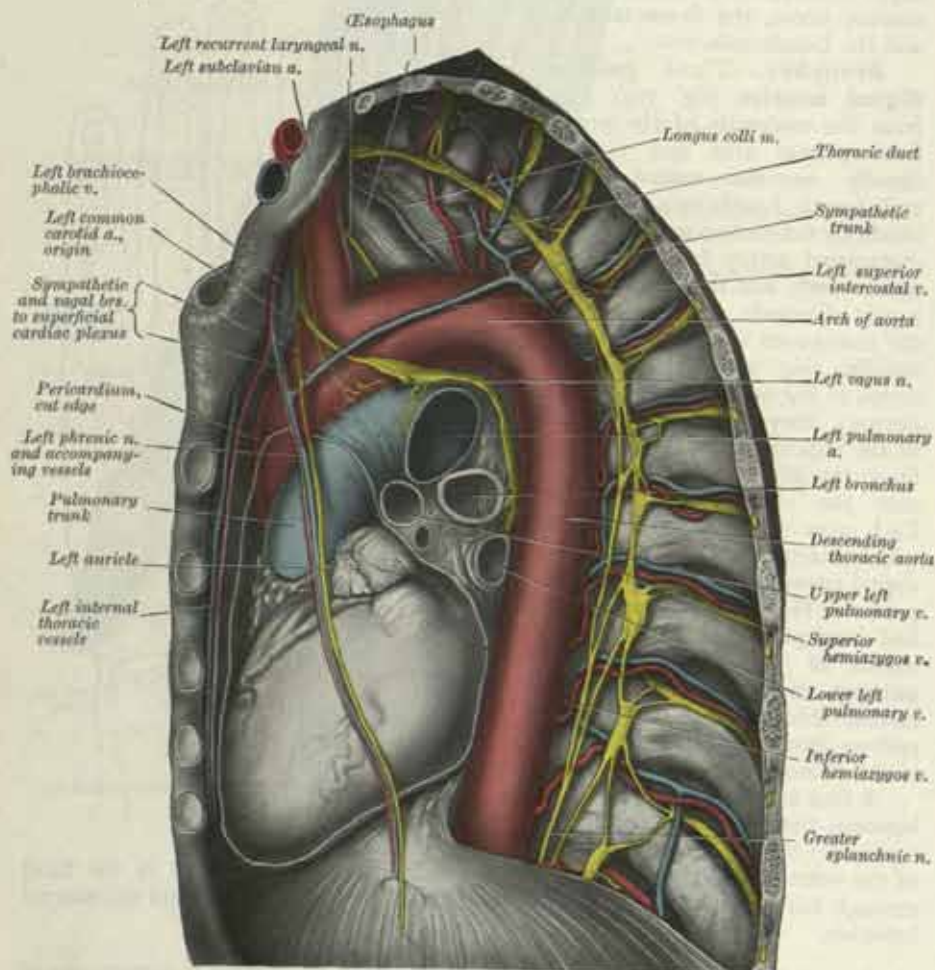
THE DESCENDING AORTA

The **descending aorta** is divided into two portions, *thoracic* and *abdominal*, in correspondence with the two great cavities in which it is situated.

THE THORACIC AORTA (figs. 721, 1158)

The **thoracic aorta** is contained in the posterior mediastinum. It begins at the lower border of the fourth thoracic vertebra, where it is continuous with the aortic

FIG. 721.—The left side of the mediastinum. The left lung and pleura have been removed, and an extensive opening has been made into the pericardial sac to expose the heart.



arch (p. 731), and ends in front of the lower border of the twelfth thoracic vertebra at the aortic hiatus in the Diaphragm. At its origin it is situated on the left of the vertebral column; as it descends it approaches the median plane, and at its termination lies in front of the column.

Relations.—It is in relation, *anteriorly*, from above downwards, with the root of the left lung, the pericardium—which separates it from the left atrium—the esophagus and the Diaphragm; *posteriorly*, with the vertebral column and the hemiazygos veins; on the *right side*, with the azygos vein and thoracic duct and, in the

lower part of its course, with the right pleura and lung; on the *left side*, with the left pleura and lung. The œsophagus, with its accompanying plexus of nerves, lies on the right side of the aorta above; but at the lower part of the thorax it is placed in front of the vessel, and, close to the Diaphragm, is placed anteriorly and to its left side.

Surface Anatomy.—The vessel can be represented by a band 2.5 cm. broad extending from the sternal end of the second left costal cartilage to a point in the median plane 2 cm. above the transpyloric plane (p. 1398).

The thoracic aorta gives off *visceral branches* to the pericardium, lungs, bronchi, and œsophagus, and *parietal branches* to the walls of the thoracic cavity.

The **pericardial branches** consist of a few small vessels which are distributed to the posterior surface of the pericardium.

The **bronchial arteries** vary in number, size and origin. There is as a rule one **right bronchial artery**, which arises from the third posterior intercostal artery, or from the upper left bronchial artery. It runs on the posterior surface of the right bronchus, dividing and subdividing along the bronchial tubes, supplying them, the areolar tissue of the lung and the bronchopulmonary lymph nodes; it also sends branches to the pericardium and the œsophagus. The **left bronchial arteries**, usually two in number, arise from the thoracic aorta, the upper opposite the fifth thoracic vertebra, and the lower just below the left bronchus. They run on the posterior surface of the left bronchus and have a distribution similar to that of the right bronchial artery.

The **œsophageal arteries**, four or five in number, arise from the front of the aorta, and pass obliquely downwards to the œsophagus; on this they form a vascular chain, which anastomoses above with the œsophageal branches of the inferior thyroid arteries, and below with ascending branches from the left phrenic and left gastric arteries.

The **mediastinal branches** are numerous small vessels which supply the lymph nodes and the areolar tissue in the posterior mediastinum.

The **phrenic branches** are small, and arise from the lower part of the thoracic aorta; they are distributed to the posterior part of the upper surface of the Diaphragm, and anastomose with the musculophrenic and pericardiophrenic arteries.

The **posterior intercostal arteries**.—There are usually nine pairs of posterior intercostal arteries derived from the thoracic aorta. They arise from the back of the vessel, and are distributed to the lower nine intercostal spaces, the first and second spaces being supplied by the superior intercostal artery (p. 774). The *right* posterior intercostal arteries are longer than the left, on account of the position of the aorta on the left side of the vertebral column; they cross the bodies of the vertebrae behind the œsophagus, thoracic duct and vena azygos, and are covered by the right lung and pleura. The *left* posterior intercostal arteries run backwards on the sides of the vertebrae and are covered by the left lung and pleura; the upper two vessels are crossed by the left superior intercostal vein, the lower vessels by the hemiazygos veins. The further course of the posterior intercostal arteries is practically the same on both sides. Opposite the heads of the ribs the sympathetic trunk passes downwards in front of them, and the splanchnic nerves also descend in front of the lower arteries.

Each artery (fig. 721) crosses its intercostal space obliquely towards the angle of the upper rib, and thence is continued forward in the costal groove. It is placed at first between the pleura and the internal (posterior) intercostal membrane, as far as the angle of the rib; from this onward it runs between the Internal intercostal and the Intercostalis intimus muscle (p. 583), and anastomoses in front with the anterior intercostal branch of the internal thoracic (internal mammary) or musculo-phrenic artery. Each artery is accompanied by a vein and a nerve, the former being above and the latter below the artery, except in the upper spaces, where the nerve is at first above the artery. The third posterior intercostal artery anastomoses with the superior intercostal artery, and may form the chief supply of the second intercostal space. The lower two posterior intercostal arteries are continued anteriorly from the intercostal spaces into the abdominal wall and anastomose with the subcostal, superior epigastric and lumbar arteries.

Each posterior intercostal artery gives off a number of branches.

The **dorsal branch** runs backwards through a space which is bounded above and below by the necks of the ribs, medially by the body of a vertebra, and laterally

by a superior costotransverse ligament. It gives off a *spinal branch*, which enters the vertebral canal through the intervertebral foramen, and is distributed to the vertebrae and to the spinal cord and its membranes, anastomosing with the spinal arteries above and below and with the artery of the opposite side. The dorsal branch then courses over the transverse process with the dorsal ramus (posterior primary ramus) of the thoracic nerve, supplies offshoots to the muscles of the back, and a cutaneous twig which accompanies the cutaneous branch of the dorsal ramus of the nerve.

The **collateral intercostal branch** comes off the posterior intercostal artery near the angle of the rib, and descends to the upper border of the rib below, along which it courses to anastomose with an intercostal branch of the internal thoracic or musculophrenic artery. The collateral branches of the lower two vessels are sometimes absent; if present, they are small and end in the abdominal muscles.

Muscular branches are given to the Intercostal and Pectoral muscles and to the Serratus anterior; they anastomose with the superior and lateral thoracic branches of the axillary artery.

The **lateral cutaneous branches** accompany the lateral cutaneous branches of the thoracic nerves.

Mammary branches are given off by the vessels in the second, third and fourth spaces; they increase considerably in size during the period of lactation.

The **right bronchial artery** may arise from the right third posterior intercostal artery (p. 793).

Applied Anatomy.—The position of the posterior intercostal vessels should be borne in mind in performing the operation of paracentesis thoracis. The puncture should never be made nearer the posterior median line than the angle of the rib, as the artery crosses the space medial to this point. In the lateral portion of the chest, where the puncture is usually made, the artery lies at the upper part of the intercostal space, and therefore the puncture should be made just above the upper border of the rib forming the lower boundary of the space.

The **subcostal arteries**, the last pair of arteries arising from the thoracic aorta, are in series with the posterior intercostal arteries, but are named *subcostal* because they are situated below the twelfth rib. Each artery runs laterally over the body of the twelfth thoracic vertebra, and behind the splanchnic nerves, the gangliated trunk of the sympathetic, the pleura and the Diaphragm. The right artery also passes behind the thoracic duct and the vena azygos, and the left behind the inferior hemiazygos vein. Each artery then enters the abdomen under cover of the lateral arcuate ligament, and courses with the twelfth thoracic nerve along the lower border of the twelfth rib, anterior to the Quadratus lumborum and posterior to the kidney. The right artery runs behind the ascending and the left behind the descending colon. Each artery then pierces the aponeurosis of origin of the Transversus abdominis, and, passing forward between this muscle and the Obliquus internus, anastomoses with the superior epigastric, lower posterior intercostal and lumbar arteries. Each subcostal artery gives off a dorsal branch, which is distributed like the dorsal branch of a posterior intercostal artery.

A small **aberrant artery** is sometimes found arising from the right side of the thoracic aorta near the origin of the right bronchial. It passes upwards and to the right behind the trachea and the œsophagus, and may anastomose with the right superior intercostal artery. It represents the remains of the right dorsal aorta (p. 170), and in a small proportion of cases is enlarged to form the first part of the right subclavian artery (p. 733).

Peculiarities.—The lumen of the aorta is occasionally found to be partly or completely obliterated, either at the aortic isthmus, or close to the point where the ductus arteriosus opens into it. This condition is known as *coarctation of the aorta*. It may be either congenital or acquired. In the former case the infant usually dies at or soon after birth. When acquired, it is apparently due to an abnormal extension of the peculiar tissue of the ductus into the aortic wall, giving rise to a simultaneous stenosis of both vessels as it contracts after birth. This form of coarctation is compatible with many years of normal life, and leads to the establishment of an extensive collateral circulation to carry blood to the aorta immediately below the stenosis.

Modern surgical methods have made it possible to explore the arch of the aorta and in cases of coarctation an obliterated section of the vessel may be removed and

replaced by an arterial graft. The extreme vascularity of the whole thoracic wall is an important feature for many arteries which arise, indirectly from the aorta, above its obliterated portion, anastomose with vessels connected with the aorta below the obliteration and the connecting channels become greatly enlarged. In the anterior thoracic wall the thoraco-acromial, lateral thoracic and the subscapular arteries from the axillary and the suprascapular from the subclavian and the first and second posterior intercostal arteries from the costocervical trunk anastomose with the third, and lower, posterior intercostal arteries and the internal thoracic artery and its terminal branches anastomose with the lower posterior intercostal arteries and the inferior epigastric arteries. The posterior intercostal arteries are always especially involved in cases of coarctation, and this fact is often confirmed on X-ray examination.

The enlargement of the scapular vessels and anastomoses in some cases renders the 'pulsating scapula' an important physical sign and this is of great diagnostic value.

In addition, a posterior, 'paraspinal', anastomosis links up the spinal branches of the vertebral artery with the homologous branches of the posterior intercostals.

Applied Anatomy.—Aneurysm of the descending thoracic aorta most commonly extends backwards along the left side of the vertebral column and leads to absorption of the bodies of the vertebræ (but not of the intervertebral discs) and of the ribs; pressure on the intercostal nerves may give rise to radiating pains in the left upper intercostal spaces; after erosion of the vertebræ the aneurysm may compress the spinal nerve-roots or ultimately the spinal cord, producing pains in the chest, back or loins, or paralysis below the site of the lesion. If the aneurysm extend forward, it may press upon and displace the heart, giving rise to palpitation and other symptoms of disease of that organ. The diagnosis of thoracic aneurysm is much facilitated by the employment of aortography.

THE ABDOMINAL AORTA (fig. 722)

The **abdominal aorta** begins at the aortic opening of the Diaphragm, in front of the lower border of the body of the last thoracic vertebra, and, descending in front of the vertebral column, ends on the body of the fourth lumbar vertebra, a little to the left of the median plane, by dividing into the two common iliac arteries. It diminishes rapidly in size, because such large branches arise from it.

Relations.—*Anteriorly* the abdominal aorta is at first related to the celiac trunk and its branches, the celiac plexus of nerves and the lesser sac of peritoneum, which intervene between it and the papillary process of the liver and the lesser omentum. Immediately below this level the aorta gives origin to the superior mesenteric artery, and is crossed by the left renal vein. The body of the pancreas, with the splenic vein closely applied to its posterior aspect, extends obliquely upwards and to the left across the abdominal aorta, but is separated from it by the vessels already mentioned. Below the pancreas, the aorta is related to the proximal parts of its testicular (or ovarian) branches, and is crossed by the third part of the duodenum. In its lowest part the aorta comes into intimate relationship with the posterior parietal peritoneum and is crossed by the root of the mesentery and its contents. The large nerves of the aortic plexus, the inferior mesenteric ganglion, and the commencement of the inferior mesenteric artery all intervene between the vessel and the peritoneum.

Posteriorly the abdominal aorta lies on the upper four lumbar vertebræ, the corresponding intervertebral discs and the anterior longitudinal ligament. The lumbar arteries, which arise from its dorsal aspect, and the third and fourth and sometimes the second left lumbar veins, which cross behind it to reach the inferior vena cava, intervene between the vessel and the ligament. The vessel may overlap the anterior border of the left Psoas major muscle to a slight extent.

On the *right side*, it is related above to the cisterna chyli and the thoracic duct, the azygos vein, and the right crus of the Diaphragm, which overlaps it and separates it from the inferior vena cava and the right celiac ganglion. Below the level of the second lumbar vertebra it is in contact with the inferior vena cava.

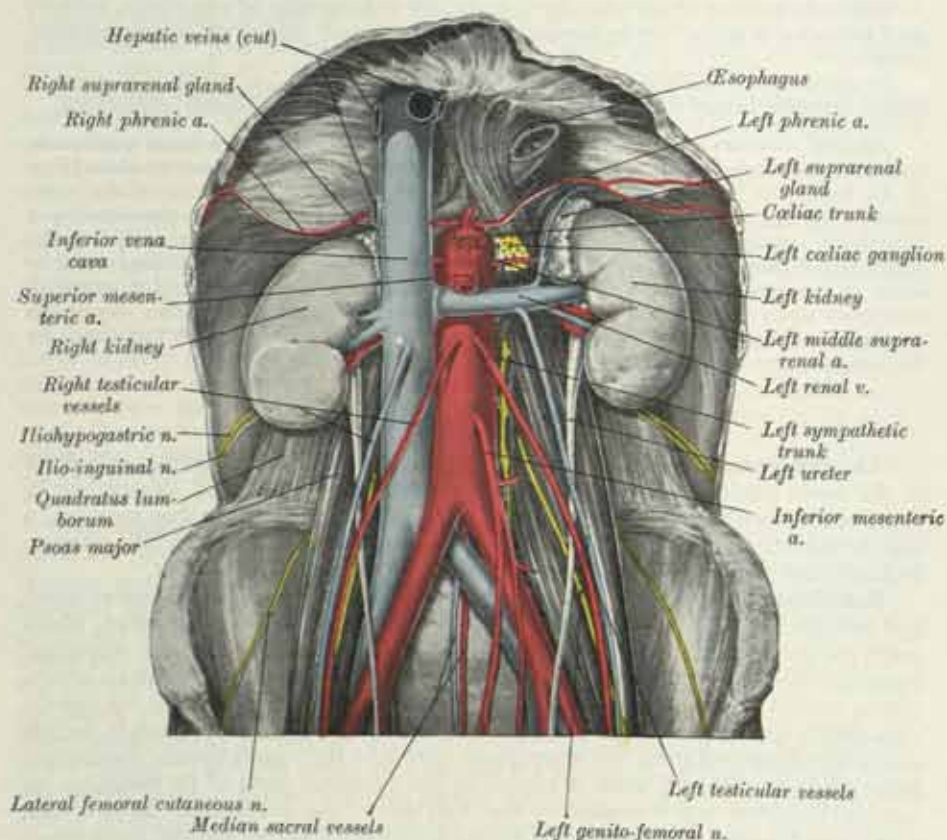
On the *left side*, it is related to the left crus of the Diaphragm and the left celiac ganglion, above. Opposite the second lumbar vertebra, it comes into relation with the duodeno-jejunal flexure and the sympathetic trunk, which continues downwards along the left side of the vessel. The fourth part of the duodenum and the inferior mesenteric vessels constitute additional relations.

Surface Anatomy.—The vessel can be represented by a band about 2 cm. wide extending from a point in the median plane 2.5 cm. above the transpyloric plane to the

point where it divides about 1 cm. below and to the left of the umbilicus. When the abdominal wall is relaxed the lowest portion of the aorta can be felt pulsating just above this point.

Applied Anatomy.—Aneurysm of the abdominal aorta occurs most frequently at its upper part, close to and often involving the celiac artery, because in this situation the vessel rapidly narrows after giving off several large branches, and its walls have lost the support afforded higher up by the crura of the Diaphragm.

FIG. 722.—The abdominal aorta and its branches.



If the aneurysm enlarges forwards it forms a pulsating tumour in the left hypochondriac or epigastric regions; by pressure upwards at the same time it may interfere with the movements of the Diaphragm and embarrass respiration, or may compress the œsophagus and produce dysphagia; pressure on the stomach and celiac plexus gives rise to dyspepsia, while jaundice may follow pressure on the bile duct and duodenum, or polyuria, albuminuria, hæmaturia and anuria pressure on the renal vessels and nerves; if the inferior vena cava is compressed there may be œdema of the lower limbs. This form of aneurysm may burst into the peritoneal cavity, behind the peritoneum, between the layers of the mesentery, or more rarely into the duodenum.

THE BRANCHES OF THE ABDOMINAL AORTA (fig. 722)

The branches of the abdominal aorta may be divided into four sets: ventral, lateral, dorsal and terminal. The ventral and lateral branches are distributed to viscera, while the dorsal branches supply the body wall.

Ventral branches.
Celiac.
Superior mesenteric.
Inferior mesenteric.

Dorsal branches.
Lumbar.
Median sacral.

Lateral branches.

Phrenic.
 Middle suprarenal.
 Renal.
 Testicular (in the male).
 Ovarian (in the female).

Terminal branches.

Common iliac.

The ventral branches, which supply the alimentary canal and its derivatives, represent fused ventral branches of the two dorsal aortæ and are therefore unpaired. The lateral branches, which supply the derivatives from the mesonephric ridges, are all paired vessels. Of the dorsal branches, the lumbar arteries, which represent persistent intersegmental arteries (p. 171), are paired, but the median sacral is an unpaired vessel. The terminal branches are paired.

THE CÆLIAC TRUNK (figs. 723, 724)

The **cæliac trunk** is a wide vessel, about 1.25 cm. long, which arises from the front of the aorta, just below the aortic opening of the Diaphragm; it passes nearly horizontally forwards above the pancreas and the splenic vein, and divides into three branches, (1) *left gastric*, (2) *hepatic*, and (3) *splenic*; it occasionally gives off one of the phrenic arteries.

Relations.—The cæliac trunk lies behind the omental bursa (lesser sac of the peritoneum), and is surrounded by the cæliac plexus of nerves, which sends branches along the three divisions of the artery. On its *right side* it is related to the right cæliac ganglion, the right crus of the Diaphragm, and the caudate process of the liver: on its *left side* to the left cæliac ganglion, the left crus of the Diaphragm, and the cardiac end of the stomach. *Below* it is related to the upper border of the pancreas and the splenic vein. The suspensory muscle of the duodenum (p. 1425) may split to encircle the artery, although it usually lies on its left side.

1. The **left gastric artery** (fig. 723), which is the smallest branch of the cæliac trunk, passes upwards and to the left, behind the omental bursa, to the cardiac end of the stomach. In its course, the left gastric artery lies close to the left phrenic artery and medial to or in front of the left suprarenal gland. At or near the cardiac end of the stomach it gives off two or three *oesophageal branches*, which ascend through the oesophageal opening of the Diaphragm and anastomose with the aortic oesophageal arteries; others supply the cardiac part of the stomach and anastomose with branches of the splenic artery. The artery then turns forwards and downwards in the left gastropancreatic fold, and runs (frequently as two branches) along the lesser curvature of the stomach to the pylorus, between the layers of the lesser omentum; it gives branches to both surfaces of the stomach and anastomoses with the right gastric artery.

2. The **hepatic artery** (figs. 723, 724) is intermediate in size between the left gastric and splenic arteries. It is accompanied by the hepatic plexus of nerves, and is first directed forwards and to the right, to the upper margin of the first part of the duodenum, passing below the medial end of the epiploic foramen (fig. 1168). It then crosses in front of the portal vein, and ascends between the layers of the lesser omentum and in front of the epiploic foramen, to the porta hepatis, where it divides into right and left branches which supply the corresponding lobes of the liver, accompanying the ramifications of the portal vein and hepatic ducts. In the lesser omentum the hepatic artery lies in front of the portal vein, and on the left of the bile-duct and its right branch crosses behind the common hepatic duct (fig. 725). The distribution of the hepatic artery within the liver is described on p. 1465.

It gives off right gastric, gastroduodenal and cystic branches.

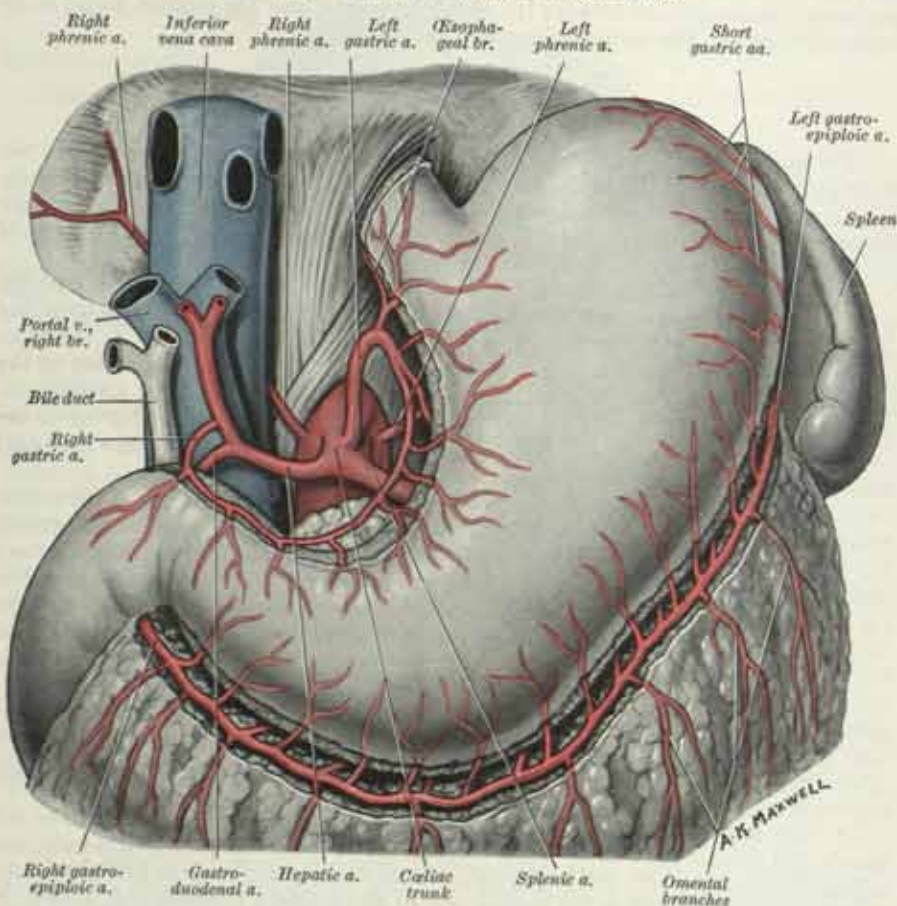
The **right gastric artery** (fig. 723) arises from the hepatic artery above the first part of the duodenum; it descends in the lesser omentum to the pyloric end of the stomach, and passes from right to left along its lesser curvature, supplying it with branches, and anastomosing with the left gastric artery.

The **gastroduodenal artery** (figs. 723, 724) is a short but large branch, which descends between the superior part of the duodenum and the neck of the pancreas, lying immediately to the right of the line along which the peritoneum is reflected from the posterior surface of the first half-inch of the duodenum (fig. 1166). At the lower

border of the duodenum it divides into the *right gastro-epiploic* and the *superior pancreaticoduodenal* arteries. Previous to its division it gives off two or three small branches to the pyloric end of the stomach and to the pancreas.

The **right gastro-epiploic artery** (figs. 723, 724), which is the larger terminal branch of the gastroduodenal artery, skirts the right margin of the omental bursa and then runs from right to left along the greater curvature of the stomach, between the layers of the greater omentum. It ends by anastomosing with the left gastro-epiploic branch of the splenic artery (p. 800). Except at the pylorus, where it is in contact with the stomach, it lies about a finger's breadth from the greater curvature.

FIG. 723.—The celiac artery and its branches.



The liver and the lesser omentum have been removed. The posterior wall of the omental bursa (lesser sac) and part of the anterior layer of the greater omentum have been taken away.

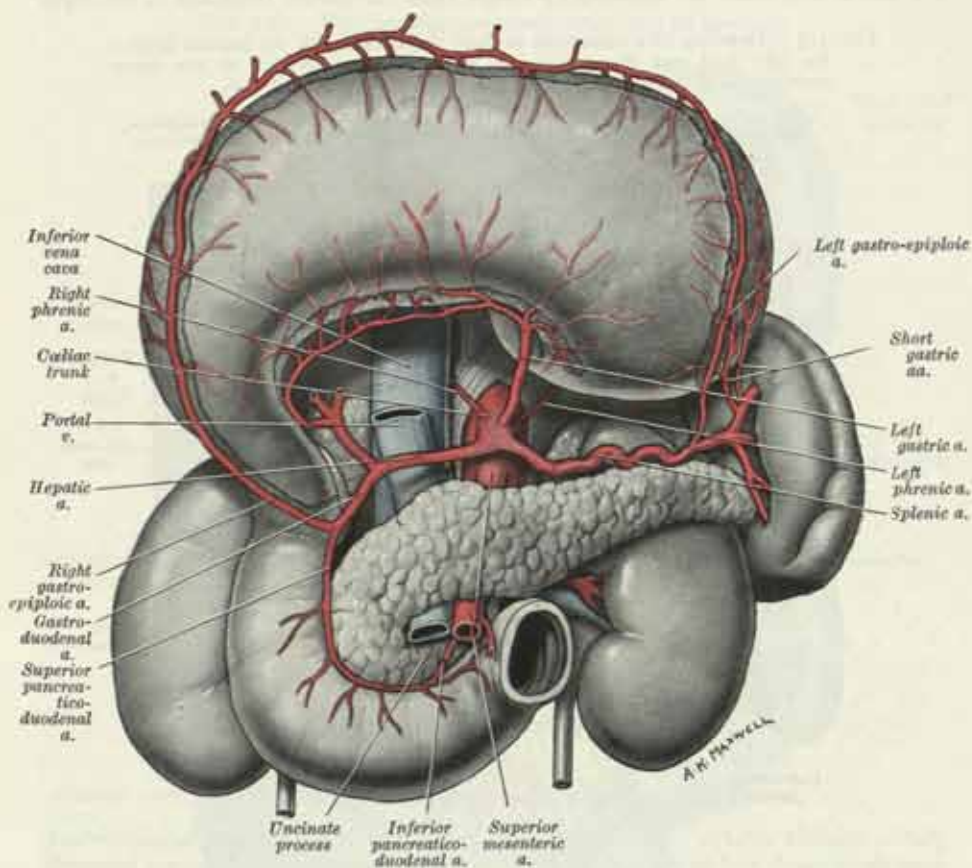
This vessel gives off numerous branches, some of which ascend to supply both surfaces of the stomach, while others descend to supply the greater omentum.

The **superior pancreaticoduodenal artery** (fig. 724) is usually represented by an anterior and a posterior vessel. The *anterior* descends on the front of the groove between the duodenum and the head of the pancreas. It supplies both of these organs, and anastomoses with the anterior division of the inferior pancreaticoduodenal branch of the superior mesenteric artery. The *posterior superior pancreaticoduodenal artery* arises from the gastroduodenal at the upper border of the superior part of the duodenum, and runs downwards and to the right in front of the portal vein and the bile duct. It then passes downwards and to the back of the head of the pancreas, supplying branches to the gland and to the duodenum, and crosses behind the bile duct, just before that structure pierces the duodenal wall. It ends by anastomosing with the posterior division of the inferior pancreaticoduodenal artery.

The **cystic artery** (fig. 725), usually arises from the right branch of the hepatic artery, and passes behind the commonhepatic and cystic ducts to gain the upper surface of the neck of the gall-bladder, on which it runs downwards and forwards before dividing into *superficial* and *deep* branches. The former ramifies on the free, and the latter on the attached, surface of the gall-bladder. Occasionally the cystic artery arises from the trunk of the hepatic artery or, rarely, from the gastroduodenal artery, and crosses in front of the bile duct to reach its destination.

3. The **splenic artery** (figs. 723, 724), which is the largest branch of the cæliac trunk, is remarkable for the tortuosity of its course. Surrounded by the

FIG. 724.—The cæliac trunk and its branches, exposed by turning the stomach upwards and removing the peritoneum on the posterior abdominal wall.*



splenic plexus of nerves, and accompanied by the splenic vein, which lies behind the pancreas, it passes horizontally to the left, behind the stomach and the omental bursa, and along the upper border of the pancreas; it crosses in front of the left suprarenal gland and the upper part of the left kidney, and enters the lienorenal ligament. On arriving near the spleen it gives origin to five or six branches which enter the hilus of the spleen (*see p. 1544*).

Branches.—The **pancreatic branches** (fig. 724) are numerous small vessels supplying the body and tail of the pancreas; they are derived from the splenic artery as it runs along the upper border of the pancreas. A *dorsal branch*,† which often arises from the celiac artery and not infrequently from the superior mesenteric, descends behind the pancreas and divides into right and left vessels. The former runs between the neck and the uncinate process of the gland and forms a

* In this and in the preceding figure the anastomosis shown between the right and left gastro-epiploic arteries is in accord with the usual description but differs from that given on p. 800.

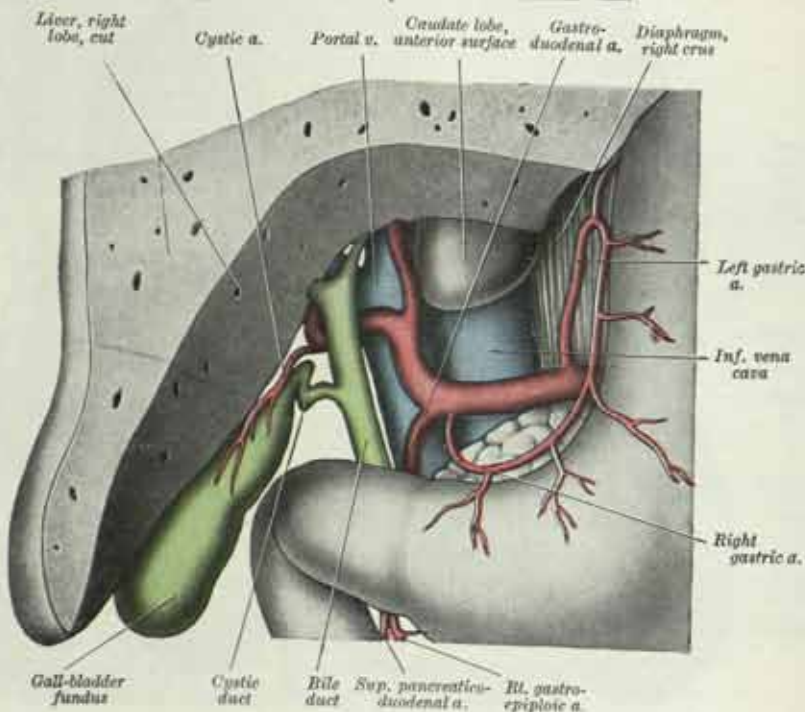
† Russell T. Woodburne and Lloyd L. Olsen, *Anat. Rec.* **111**, 1951.

prepancreatic arterial arch with a branch from the anterior superior pancreaticoduodenal: the latter runs to the left along the inferior border of the gland to reach the tail.

The **short gastric arteries** (fig. 724) are from five to seven small branches which arise from the end of the splenic artery, and from its terminal divisions. They pass between the layers of the gastrosplenic ligament, and are distributed to the fundus of the stomach, anastomosing with branches of the left gastric and left gastro-epiploic arteries.

The **left gastro-epiploic artery*** (fig. 724), which is the largest of the branches of the splenic artery, arises near the hilus of the spleen and runs obliquely downwards, forwards and to the right. It sends several branches through the gastro-splenic ligament to be distributed to the upper third or less of the greater curvature, and these are appreciably longer than the gastric branches of the right

FIG. 725.—Drawing of a dissection to show the relations of the hepatic artery, the bile duct and the portal vein after complete removal of the lesser omentum and the peritoneum on the posterior abdominal wall.



gastro-epiploic artery. Its terminal part gives off a large omental branch which runs downwards and to the right in the greater omentum, and itself curves forwards at a higher level to join the right gastro-epiploic. The looped course of the terminal part of the left gastro-epiploic leaves a portion of the greater curvature devoid of branches in its upper part. In the operation of partial gastrectomy the incision in the stomach wall passes through this avascular gap and, on the right side the gastro-colic omentum is divided below the right gastro-epiploic artery, cutting all its colic branches. The greater omentum survives because its supply from the large omental branch of the left gastro-epiploic artery has not been damaged.†

The **splenic branches** enter the hilus of the spleen between the two layers of the lienorenal ligament. Their distribution within the spleen is described with the anatomy of that organ (p. 1544).

Peculiarities.—Although the arrangement of the coeliac trunk and its branches is fairly constant, three variations are worthy of mention. (1) An *accessory right hepatic artery* sometimes arises from the superior mesenteric artery and runs upwards and to the right, passing behind the portal vein to gain the right extremity of the porta

* N. A. Michels. "Blood supply and Anatomy of the Upper abdominal Organs." Pitman Medical Publishing Co., Ltd., London, 1956.

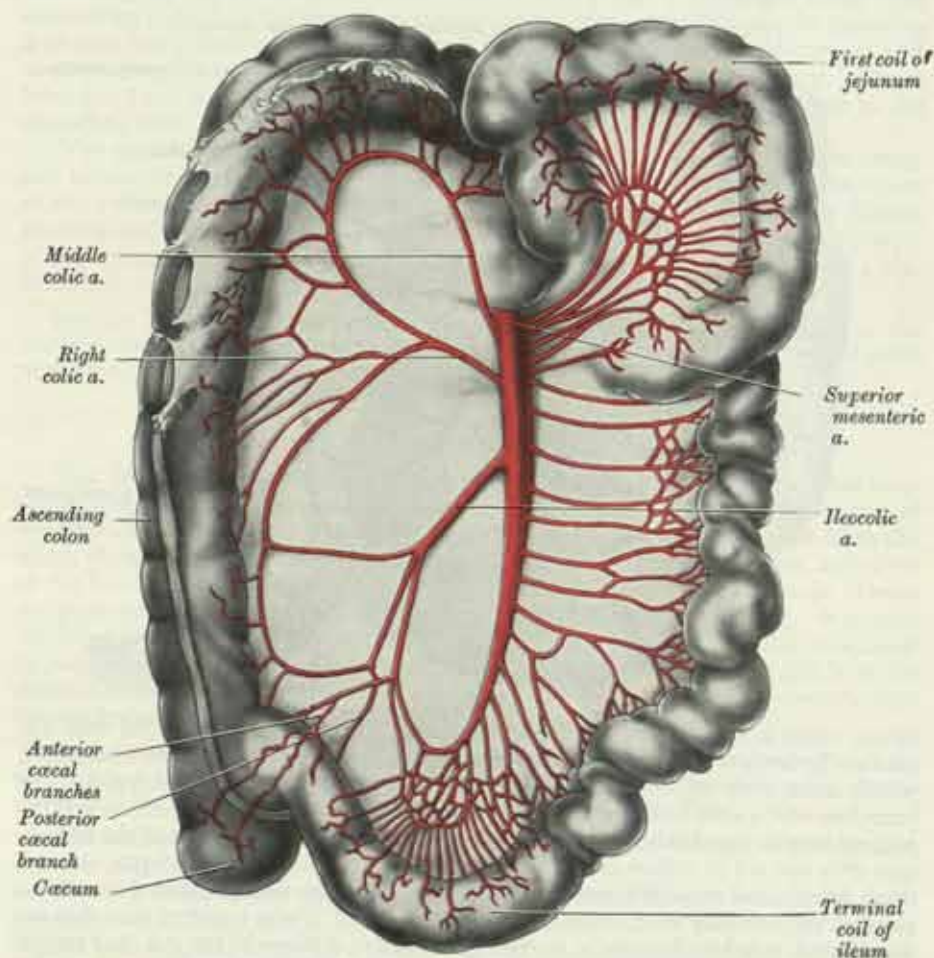
† R. E. Horton, *Guy's Hosp. Reports*, 101, No. 2, 1952.

hepatis. (2) An *accessory left hepatic artery* not infrequently arises from the left gastric artery and courses to the right between the two layers of the lesser omentum. It enters the lower part of the fissure for the ligamentum venosum to gain the left extremity of the porta hepatis. (3) An *accessory left gastric artery* may arise from the left branch of the hepatic artery and traverse the lesser omentum to gain the lesser curvature of the stomach.

THE SUPERIOR MESENTERIC ARTERY (fig. 726)

The **superior mesenteric artery** supplies the whole of the small intestine except the superior part of the duodenum; it also supplies the cæcum and the ascending colon and most of the transverse colon. It arises from the front of the aorta about

FIG. 726.—The Superior mesenteric artery and its branches.



The first coil of the jejunum and the terminal coil of the ileum have been spread out to show the arrangement of the arteries, see text (p. 802).

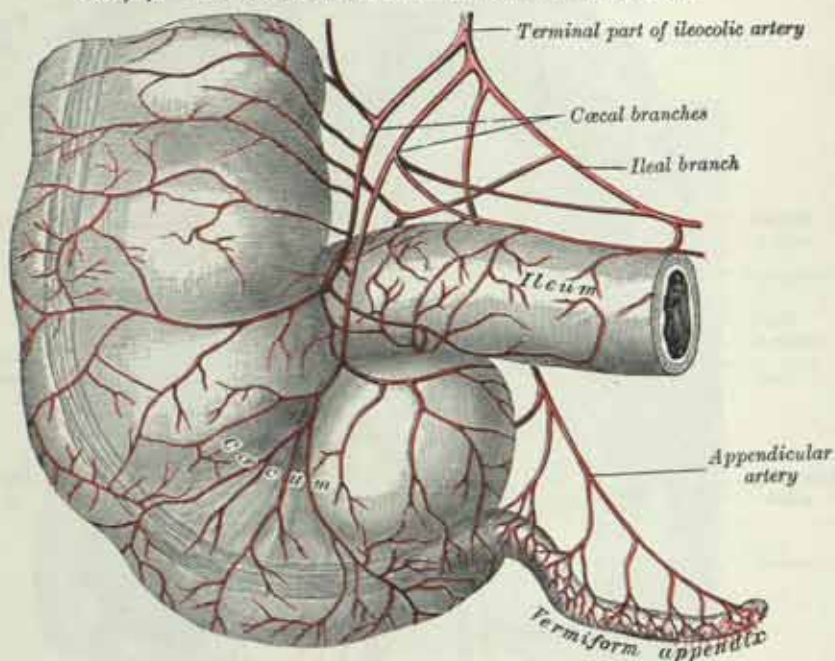
1 cm. below the celiac trunk, and is crossed at its origin by the splenic vein and the body of the pancreas. Near its origin it is separated from the front of the aorta by the left renal vein. Thereafter it passes downwards and forwards, anterior to the uncinate process of the head of the pancreas and the horizontal part of the duodenum, and descends between the layers of the mesentery and near its root until it reaches the right iliac fossa, where, considerably diminished in size, it anastomoses with one of its own branches, viz., the ileocolic artery. In its course it crosses in front of the inferior vena cava, the right ureter, and Psoas major, and forms an arch, the convexity of which is directed forwards, downwards, and to the left side. It is

accompanied by the superior mesenteric vein, which lies to its right side, and is surrounded by the superior mesenteric plexus of nerves.

Branches.—The **inferior pancreaticoduodenal artery** (fig. 724) springs from the superior mesenteric artery or from its first jejunal branch, opposite the upper border of the horizontal part of the duodenum. Usually it divides at once into an anterior and a posterior branch. The *anterior branch* courses to the right in front of the head of the pancreas and then ascends to anastomose with the anterior superior pancreaticoduodenal artery. The *posterior branch* passes upwards and to the right behind the head of the pancreas, which it sometimes pierces, to anastomose with the posterior superior pancreaticoduodenal artery. Both branches supply the head of the pancreas, including its uncinat process, and the duodenum.

The **jejunal and ileal branches** (fig. 726) arise from the left side of the superior mesenteric artery. They are usually from twelve to fifteen in number, and are distributed to the jejunum and ileum, with the exception of the terminal part of the

FIG. 727.—The arteries of the cæcum and vermiform appendix.



latter, which is supplied by the ileocolic artery. They run nearly parallel with one another between the layers of the mesentery, each vessel dividing into two branches, which unite with adjacent branches, to form a series of arches (fig. 726). The branches which arise from the arches unite to form a second series of arches, and the process may be repeated three or four times. In the short, upper part of the mesentery only one set of arches exists, but as the mesentery increases in depth, second, third, fourth, and even fifth groups are present. From the terminal arches numerous small straight vessels arise which supply the intestine. These terminal branches are distributed, roughly alternately, to the right and left surfaces of the gut, and neighbouring vessels do not anastomose with one another.* As a rule the jejunal arteries are longer and less numerous than the ileal arteries. From both groups small branches are given off to the lymph nodes and other structures between the layers of the mesentery.

The **ileocolic artery** (fig. 726) is the lowest of the branches arising from the concavity of the superior mesenteric artery. It passes downwards and to the right behind the peritoneum, towards the right iliac fossa, where it divides into a superior and an inferior branch; the superior branch anastomoses with the right colic artery, the inferior with the end of the superior mesenteric artery. In its course, the ileocolic artery crosses in front of the right ureter, testicular (or ovarian) vessels and Psoas major muscle.

* A. J. Colkinis, *J. Anat.*, 64, 1930.

The inferior branch of the ileocolic runs towards the upper border of the ileocolic junction and supplies the following branches (fig. 727): (*a*) *colic*, which passes upwards on the ascending colon; (*b*) *anterior* and *posterior caecal*, which are distributed to the front and back of the caecum; (*c*) an *appendicular artery*, which descends behind the termination of the ileum and enters the mesentery of the vermiform appendix; after giving off a recurrent branch, which anastomoses with a branch from the posterior caecal artery, it runs at first close to and later in the free margin of the mesentery of the vermiform appendix, but its terminal part is in actual contact with the appendicular wall; and (*d*) *ileal*, which runs upwards and to the left on the lower part of the ileum, and anastomoses with the termination of the superior mesenteric artery.

The **right colic artery** (fig. 726) arises from near the middle of the concavity of the superior mesenteric artery, or from a stem common to it and the ileocolic artery. It passes to the right behind the peritoneum, and in front of the right testicular (or ovarian) artery and vein, the right ureter, and the Psoas major, towards the ascending colon. Sometimes the vessel lies at a higher level, and crosses the descending part of the duodenum and the lower end of the right kidney. At the colon it divides into a descending branch, which anastomoses with the ileocolic artery, and an ascending branch, which anastomoses with the middle colic artery. These branches form arches, from the convexity of which vessels are distributed to the ascending colon.

The **middle colic artery** (fig. 726) arises from the superior mesenteric artery just below the pancreas and, passing downwards and forwards between the layers of the transverse mesocolon, divides into a right and a left branch; the former anastomoses with the right colic artery; the latter with the left colic artery, a branch of the inferior mesenteric artery. The arches thus formed are placed 3 or 4 cm. from the transverse colon, to which they distribute branches.

Surface Anatomy.—The superior mesenteric artery arises at or just above the transpyloric plane. From here it runs with a gentle convexity to the left to the point of intersection of the transtubercular and right lateral planes.

THE INFERIOR MESENTERIC ARTERY (fig. 728)

The **inferior mesenteric artery** supplies the terminal part of the transverse colon, the whole of the descending colon, the sigmoid colon and the greater part of the rectum. It is smaller than the superior mesenteric artery, and arises from the aorta, about 3 or 4 cm. above its division into the common iliac arteries, and close to the lower border of the horizontal part of the duodenum. It descends behind the peritoneum, lying at first in front of the aorta, and then on its left side. It crosses the left common iliac artery on the medial side of the left ureter, and is continued between the two layers of the sigmoid mesocolon into the lesser (true) pelvis as the *superior rectal artery*. In the lower part of its course, the inferior mesenteric vein lies on its lateral side.

Surface Anatomy.—The vessel can be represented by a line, beginning 2.5 cm. above the umbilicus and 1 cm. lateral to the median plane, and thence running downwards and slightly to the left to a point 4 cm. below the umbilicus.

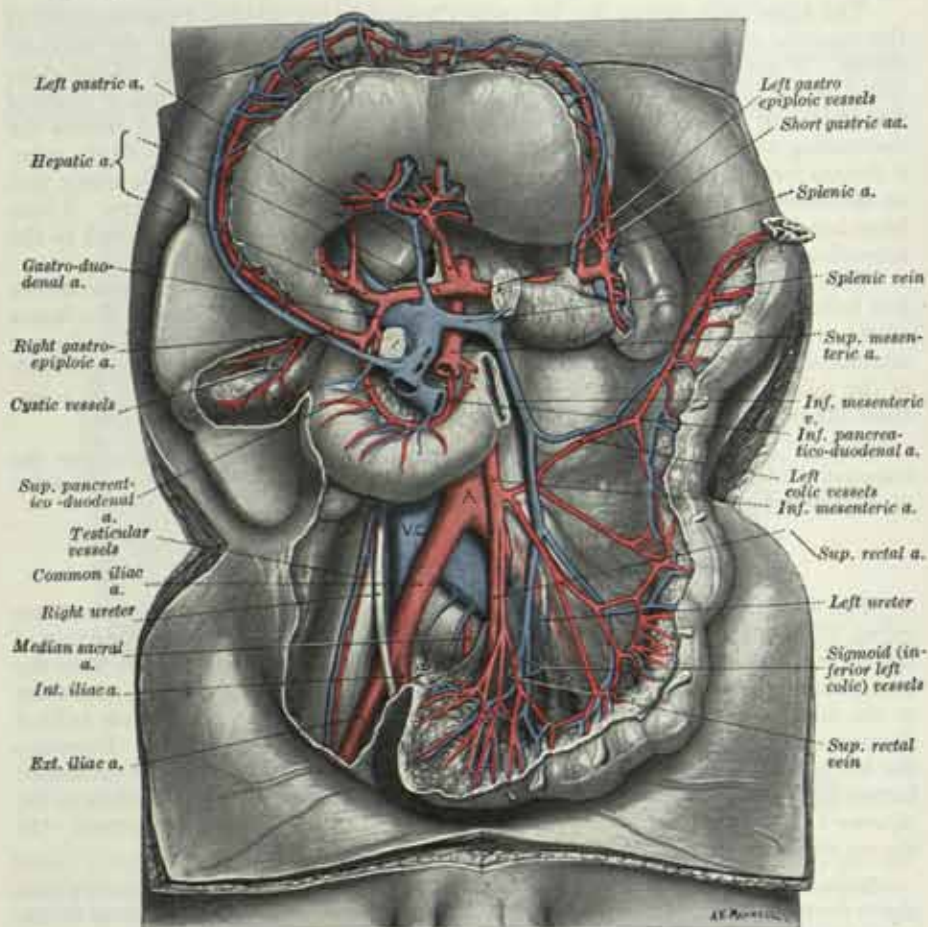
The inferior mesenteric artery gives off superior and inferior left colic and superior rectal branches.

The **left colic artery** (fig. 728) runs upwards and to the left behind the peritoneum and in front of the Psoas major, and, after a short but variable course, divides into an ascending and a descending branch; the trunk or the branches of the artery cross the left ureter and left testicular vessels. The ascending branch passes in front of the left kidney and then between the two layers of the transverse mesocolon, where it anastomoses with the middle colic artery; the descending branch anastomoses with the highest sigmoid artery. From the arches formed by these anastomoses branches are distributed to the left half of the transverse colon, and to the descending colon.

The **sigmoid (inferior left colic) arteries** (figs. 728, 729), two or three in number, run obliquely downwards and to the left behind the peritoneum and in front of the left Psoas major, ureter, and testicular vessel. Their branches supply the lower part of the descending colon and the sigmoid colon, anastomosing above with the left colic artery, and below with the superior rectal artery. The latter anastomosis, however, is dependent on one or more very slender connexions.

The **superior rectal artery** (figs. 728, 729), which is the continuation of the inferior mesenteric artery, descends into the pelvis between the layers of the sigmoid mesocolon, crossing, in its course, the left common iliac vessels. It divides, opposite the third sacral vertebra, into two branches; these descend one on each side of the rectum, and supply its mucous membrane as far as the anal canal, and the upper two-thirds of its muscular coat; about halfway down the rectum the two arteries break up into several small branches. These pierce the muscular coat of the bowel and

FIG. 728.—A dissection to display the inferior mesenteric vessels and their branches.



Note.—The stomach has been turned upwards and the whole of the jejunum and ileum, the caecum, ascending colon and transverse colon have been removed, together with a portion of the pancreas.

run straight downwards in the wall of the gut between its muscular and mucous coats, to the level of the Sphincter ani internus; here by anastomoses with one another they form a system of loops around the lower end of the rectum, and communicate with the middle rectal artery, which is a branch of the internal iliac artery, and with the inferior rectal artery, which arises from the internal pudendal artery.

Applied Anatomy.—As a result of the free anastomoses between the left colic arteries a continuous 'marginal artery' descends near the gut from the left colic flexure to the distal end of the sigmoid colon, where it ends, because the superior rectal artery does not divide into arch-forming branches. The point where the lowest sigmoid artery anastomoses with the superior rectal artery is therefore sometimes named the 'critical point'. Ligature of these two arteries will almost certainly result in gangrene of the part of the rectum which is supplied by them. If, however, the inferior mesenteric artery be tied proximal to the origin of its lowest sigmoid branch, blood can pass through the latter branch into the superior rectal artery.

THE MIDDLE SUPRARENAL ARTERIES

The **middle suprarenal arteries** are two small vessels which arise, one from each side of the aorta, opposite the superior mesenteric artery. Each artery passes laterally and slightly upwards, over the crus of the Diaphragm, to the suprarenal gland, where it anastomoses with suprarenal branches of the phrenic and renal arteries. On the right side the artery passes behind the inferior vena cava and is closely related to the celiac ganglion. On the left side it comes into relation with the celiac ganglion, the splenic artery and the upper border of the pancreas. The distribution of the suprarenal arteries is described on p. 1538.

THE RENAL ARTERIES (fig. 722)

The **renal arteries** are two large trunks which arise from the sides of the aorta immediately below the superior mesenteric artery. Each is directed across the corresponding crus of the Diaphragm, nearly at right angles to the aorta. The *right* is longer than the left, on account of the position of the aorta; it passes behind the inferior vena cava, the right renal vein, the head of the pancreas, and the descending part of the duodenum. The *left* is a little higher than the right; it lies behind the left renal vein, the body of the pancreas and the splenic vein, and may be crossed by the inferior mesenteric vein. Just before reaching the hilum of the kidney, each artery divides into four or five branches; most of these lie between the renal vein and the pelvis of the ureter, the vein being in front, and the pelvis behind, but one or more branches are usually situated behind the pelvis. Each renal artery gives off some small *inferior suprarenal branches* (p. 171) to the suprarenal gland, and supplies twigs to the ureter and the surrounding cellular tissue and muscles.

Surface Anatomy.—The renal arteries can be represented by broad lines running laterally for 4 cm. from the lateral margins of the aorta just below the transpyloric plane. In the case of the artery of the left side the line should incline upwards across the transpyloric plane.

One or two *accessory renal arteries* are frequently found, more especially on the left side: they usually arise from the aorta, and may come off above or below the main artery, the former being slightly the more common position. Instead of entering the kidney at the hilus, they usually pierce the upper or lower part of the kidney; an accessory artery to the lower part of the kidney crosses in front of the ureter and, on the right side, usually in front of the inferior vena cava. These vessels are "end arteries".

THE TESTICULAR ARTERIES (fig. 722)

The **testicular arteries** are two long, slender vessels, which arise from the front of the aorta a little below the renal arteries and are distributed to the testes. Each passes obliquely downwards and laterally behind the peritoneum, resting on the Psoas major; the right artery lies in front of the inferior vena cava and behind the horizontal portion of the duodenum, the right colic and ileocolic arteries, and the terminal part of the ileum; the left artery passes behind the inferior mesenteric vein, the left colic artery, and the lower part of the descending colon. Each artery passes in front of the genitofemoral nerve, the ureter and the lower part of the external iliac artery on its way to reach the deep inguinal ring, where it enters the spermatic cord. Accompanied by the other constituents of the spermatic cord, it traverses the inguinal canal and enters the scrotum. At the upper end of the posterior border of the testis it divides into two branches which pass on to the medial and lateral surfaces and after piercing the tunica albuginea end in the tunica vasculosa (p. 1494). From the latter terminal branches pass into the substance of the testis at various points over the free surface. Some of these vessels pass into the mediastinum testis and then loop back again before reaching their distribution.* In the abdomen the testicular artery supplies small branches to the fat around the kidney, the ureter and the iliac lymph nodes; in the inguinal canal it gives one or two twigs to the Cremaster.

Not infrequently the right testicular artery passes behind the inferior vena cava. It should be remembered that the testicular arteries represent persistent lateral splanchnic branches of the aorta (p. 171) and that as these vessels enter the mesonephros they

* R. G. Harrison and A. E. Barclay, *Brit. J. Urol.*, 20, 2, 1948

cross ventral to the supracardinal vein but dorsal to the subcardinal vein. Under normal conditions of development the lateral splanchnic artery which persists as the right testicular artery passes caudal to the particular supra-subcardinal anastomosis which persists to take part in the formation of the inferior vena cava. When it passes cranial to this anastomosis the right testicular artery will lie behind the inferior vena cava in the adult.

THE OVARIAN ARTERIES

The **ovarian arteries** in the female correspond to the testicular arteries in the male, but they enter the pelvis and supply the ovaries (fig. 732). The origin and course of the first part of each artery are the same as those of the testicular artery, but on arriving at the brim of the lesser (true) pelvis the artery crosses the upper parts of the external iliac artery and vein, and enters the pelvic cavity. It then runs medially in the infundibulopelvic ligament and gains the broad ligament of the uterus, where it lies below the uterine tube. At the level of the ovary it passes backwards in the mesovarium and breaks up into branches which are distributed to the ovary. Small branches are given to the ureter and the uterine tube, and one passes to the side of the uterus, and unites with the uterine artery. Other offsets are continued on the round ligament of the uterus, through the inguinal canal, to the skin of the labium majus and the groin.

At an early period of intrauterine life, when the testes or ovaries lie by the side of the vertebral column, below the kidneys, the testicular and ovarian arteries are short; but with the descent of the testicles into the scrotum and of the ovaries into the pelvis, the arteries gradually lengthen.

THE PHRENIC ARTERIES (fig. 722)

The **phrenic arteries** are two small vessels which supply the Diaphragm. They present much variety in their origins; they may arise separately from the front of the aorta, immediately above the celiac trunk, or by a common trunk, which may spring either from the aorta or from the celiac trunk; sometimes one artery is derived from the aorta, and the other from one of the renal arteries. From its origin the artery runs upwards and laterally in front of the crus of the Diaphragm and close to the medial border of the suprarenal gland. The left phrenic passes behind the œsophagus, and runs forwards on the left side of the œsophageal opening. The right phrenic passes behind the inferior vena cava, and along the right side of the opening which transmits that vein. Near the posterior border of the central tendon of the Diaphragm each vessel divides into a medial and a lateral branch. The medial branch curves forwards, and anastomoses with its fellow of the opposite side in front of the central tendon, and with the musculophrenic and pericardiophrenic arteries. The lateral branch passes towards the side of the thorax, and anastomoses with the lower posterior intercostal arteries, and with the musculophrenic artery. The lateral branch of the right artery gives off a few twigs to the inferior vena cava; and the left artery sends some branches to the œsophagus. Each vessel gives off two or three small *superior suprarenal branches* to the suprarenal gland of its own side. The liver and the spleen also receive a few twigs from the right and left vessels respectively.

THE LUMBAR ARTERIES

The **lumbar arteries** are in series with the posterior intercostal arteries and represent persistent intersegmental somatic branches of the aorta in the embryo (p. 171). Usually four in number on each side, they arise from the back of the aorta, opposite the bodies of the upper four lumbar vertebrae. A fifth pair, small in size, occasionally arises from the median sacral artery; but the lumbar branches of the ilio-lumbar arteries usually take the place of the fifth pair. The lumbar arteries run laterally and backwards on the bodies of the lumbar vertebrae, deep to the sympathetic trunks, to reach the intervals between the adjacent transverse processes, and are then continued into the abdominal wall. The arteries of the right side pass deep to the inferior vena cava, and the upper two on the right side (the first only on the left side) run deep to the corresponding crus of the Diaphragm. The arteries of both sides pass under cover of the tendinous arches which give origin to the Psoas major, and are continued behind this muscle and the lumbar plexus. They then cross the Quadratus lumborum, the upper three arteries running behind, the last usually in front of that muscle. At the lateral border of the Quadratus lumborum they pierce the posterior aponeurosis of the Transversus abdominis, and pass forwards between this muscle

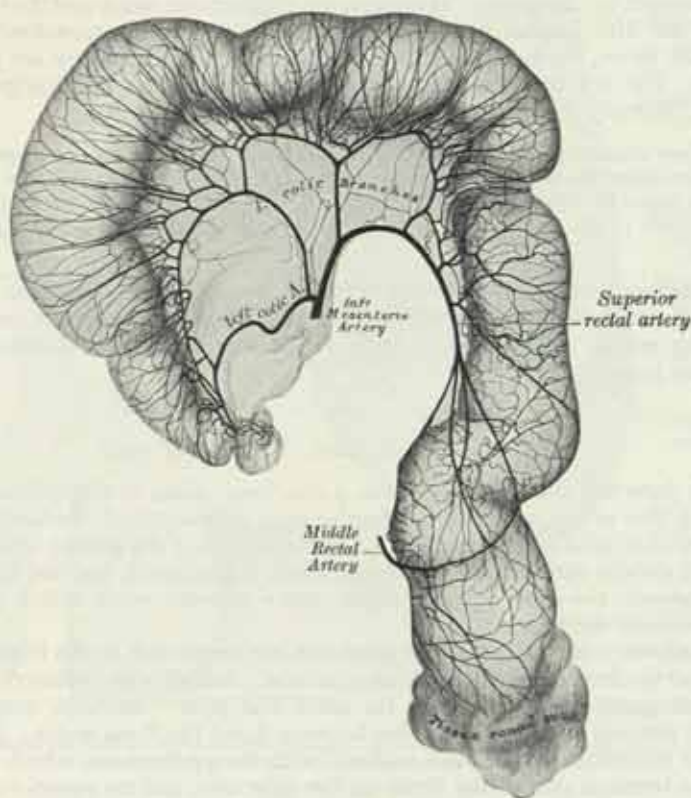
and the Internal oblique. They anastomose with one another and with the lower posterior intercostal, subcostal, iliolumbar, deep circumflex iliac and inferior epigastric arteries.

Branches.—Each lumbar artery gives off a *dorsal ramus* which, passing backwards between the transverse processes, is distributed to the muscles and skin of the back. The posterior ramus also furnishes a *spinal branch*, which enters the vertebral canal and supplies its contents, anastomosing with the arteries above and below it, and with the artery of the opposite side. Branches are also given by the lumbar arteries and their dorsal rami to the neighbouring muscles.

THE MEDIAN SACRAL ARTERY (fig. 722)

The **median sacral artery** is a small vessel which arises from the back of the aorta a little above its bifurcation. It descends in the median plane in front of the fourth and fifth lumbar vertebrae, the sacrum and coccyx, and ends in the coccygeal body.

FIG. 729.—The sigmoid colon and rectum, showing the distribution of the branches of the inferior mesenteric artery, and their anastomoses. (From a preparation by Hamilton Drummond.)



At the level of the fifth lumbar vertebra it is crossed by the left common iliac vein, and it frequently gives off on each side a small lumbar artery (*arteria lumbalis ima*). Minute branches are said to pass from it to the posterior surface of the rectum. On the last lumbar vertebra it anastomoses with the lumbar branch of the iliolumbar artery; in front of the sacrum it anastomoses with the lateral sacral arteries, and sends offsets into the pelvic sacral foramina.

THE COMMON ILIAC ARTERIES (fig. 722)

The abdominal aorta divides, on the left part of the body of the fourth lumbar vertebra, into the right and left **common iliac arteries**. Each artery passes downwards and laterally, and divides opposite the intervertebral disc between the last lumbar vertebra and the sacrum, into two branches, termed the *external iliac* and

internal iliac arteries: the former supplies the greater part of the lower limb; the latter, the viscera and parietes of the pelvis, the perineum and the gluteal region.

The **right common iliac artery** (fig. 722), about 5 cm. long, passes obliquely across the body of the last lumbar vertebra. *In front*, it is crossed by sympathetic fibres passing to the superior hypogastric plexus, and, at its point of division, by the ureter; throughout its course it is covered with the parietal peritoneum, by which it is separated from the coils of the small intestine. *Behind*, it is separated from the bodies of the fourth and fifth lumbar vertebrae and the intervening intervertebral disc by the sympathetic trunk, the terminal parts of the two common iliac veins and the commencement of the inferior vena cava. The obturator nerve, the lumbosacral trunk and the ilio-lumbar artery are situated more deeply and traverse the fatty tissue which occupies the interval between the last lumbar vertebra and the Psoas major muscle. *Laterally* it is in relation above with the inferior vena cava and the right common iliac vein; below, with the Psoas major. *Medially* its upper part is related to the left common iliac vein.

The **left common iliac artery** (fig. 722), about 4 cm. long, is in relation, *in front*, with the peritoneum, the small intestine, sympathetic fibres passing to the superior hypogastric plexus, and the superior rectal artery, and is crossed at its point of bifurcation by the ureter. It rests on the sympathetic trunk and the bodies of the fourth and fifth lumbar vertebrae, and the intervening intervertebral disc. The obturator nerve, the lumbosacral trunk and the ilio-lumbar artery are placed more deeply. The left common iliac vein lies partly *medial* to, and partly *behind*, the artery; *laterally* the artery is in relation with the Psoas major.

Surface Anatomy.—The vessel corresponds on each side to the upper third of a broad line from the bifurcation of the aorta (p. 795) to the point midway between the anterior superior iliac spine and the pubic symphysis. The *external iliac artery* corresponds to the lower two-thirds of this line which should be slightly convex laterally.

Branches.—In addition to the terminal branches each common iliac artery gives off small branches to the peritoneum, Psoas major, ureter, and the surrounding areolar tissue; occasionally it gives origin to the ilio-lumbar and to accessory renal arteries.

THE INTERNAL ILIAC ARTERY (fig. 730)

The **internal iliac artery**, about 4 cm. long, arises at the bifurcation of the common iliac artery, opposite the lumbosacral intervertebral disc and in front of the sacro-iliac joint; it descends to the upper margin of the greater sciatic foramen, where it divides into an *anterior* trunk, which continues in the line of the parent vessel towards the spine of the ischium, and a *posterior* trunk, which passes backwards towards the foramen.

Relations.—It is in relation *in front* with the ureter and, in the female, with the ovary and the fimbriated end of the uterine tube; *behind*, with the internal iliac vein, the lumbosacral nerve-trunk and the sacro-iliac joint; *laterally*, near its origin, with the external iliac vein, which lies between it and the Psoas major; lower down, with the obturator nerve; and *medially* with the peritoneum, which separates it from the terminal part of the ileum on the right side, and the sigmoid colon on the left side, and with some of the tributaries of the internal iliac vein.

In the foetus, the internal iliac artery is twice as large as the external iliac artery, and is the direct continuation of the common iliac artery. It ascends on the back of the anterior wall of the abdomen to the umbilicus, converging on its fellow of the opposite side. Having passed through the umbilical opening, the two arteries, now termed *umbilical*, enter the umbilical cord, where they are coiled round the umbilical vein, and ultimately ramify in the placenta.

At birth, when the placental circulation ceases, only the pelvic portion of the artery remains patent and constitutes the internal iliac artery and the first part of the superior vesical artery of the adult; the remainder of the vessel is converted into a fibrous cord, termed the *lateral umbilical ligament*, which extends from the pelvis to the umbilicus. In the male, the patent portion of the umbilical artery usually gives off the artery to the ductus (vas) deferens.

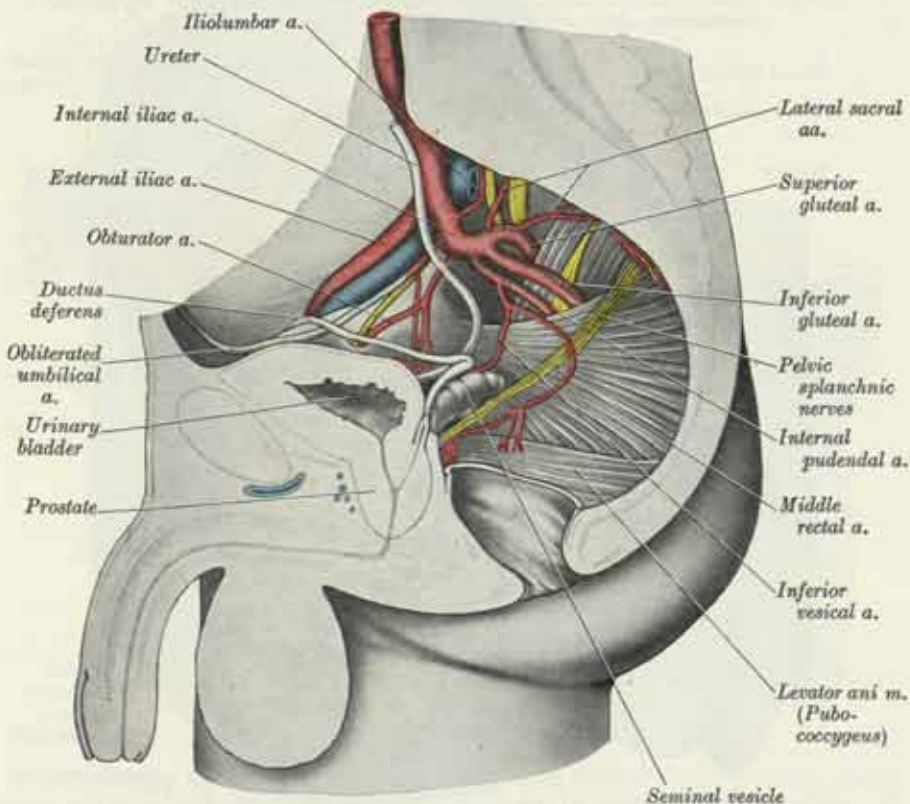
Branches from the anterior trunk.—The **superior vesical artery** (fig. 730)

supplies numerous branches to the upper part of the bladder. From one of these the *artery to the ductus (vas) deferens*, occasionally takes origin and accompanies the ductus in its course to the testis, where it anastomoses with the testicular artery. Other branches supply the ureter. The first part of the superior vesical artery is the proximal, patent, portion of the fetal umbilical artery.

The **inferior vesical artery** (fig. 730) frequently arises in common with the middle rectal artery, and is distributed to the fundus of the bladder, the prostate, the seminal vesicles and the lower part of the ureter. The branches to the prostate communicate with the corresponding vessels of the opposite side. The inferior vesical artery may sometimes give origin to the artery to the ductus deferens.

The **middle rectal artery** (figs. 729, 730) usually arises with the preceding vessel. It is distributed to the muscular coats of the lower part of the rectum,

FIG. 730.—The arteries of the pelvis. Right side.



The internal iliac vein and its tributaries have been removed; the rectum has been divided just above the anal canal and its upper part has been taken away.

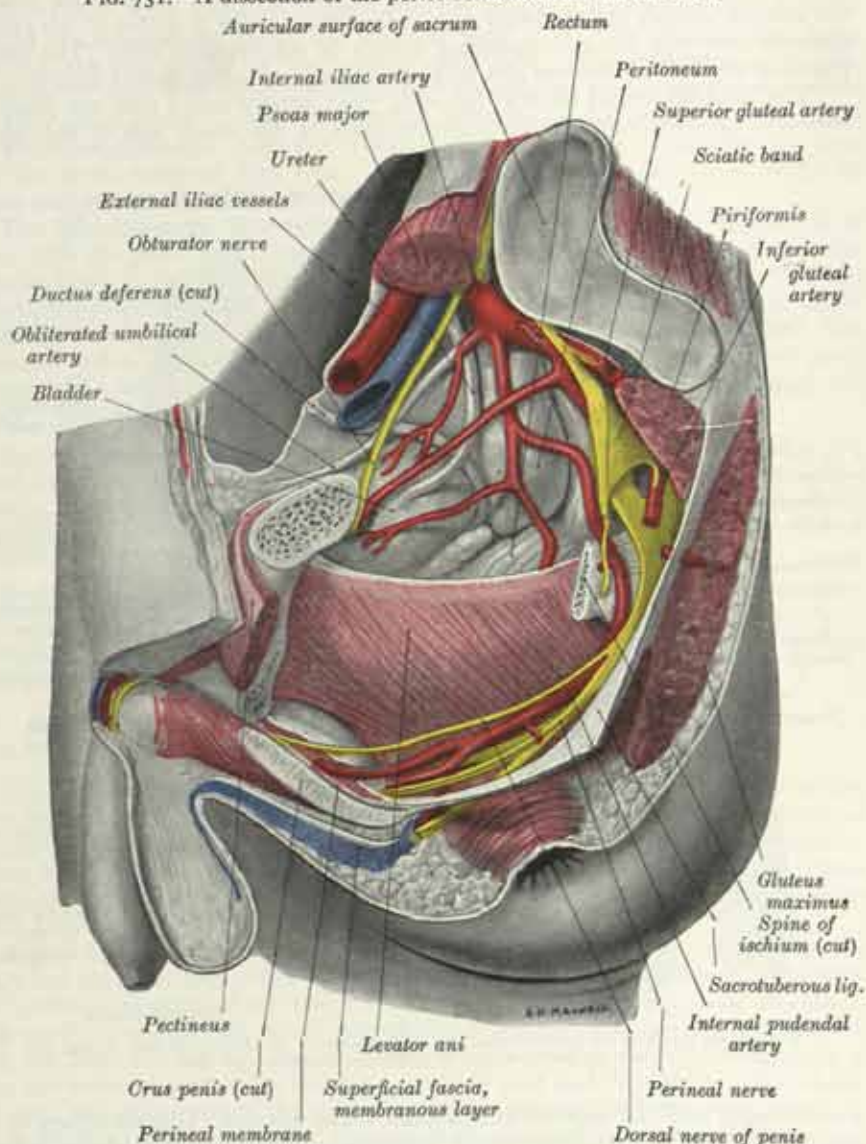
anastomosing with the superior and inferior rectal arteries. It gives offshoots to the seminal vesicles and prostate, which anastomose with branches of the inferior vesical artery.

The **uterine artery** (fig. 732) runs medially on the Levator ani and towards the cervix uteri; about 2 cm. from the cervix it crosses above and in front of the ureter—to which it supplies a small branch—and above the lateral fornix of the vagina. Reaching the side of the uterus it ascends in a tortuous manner between the two layers of the broad ligament to the junction of the uterine tube and uterus. It then runs laterally towards the hilus of the ovary, and ends by joining with the ovarian artery. It supplies branches to the cervix uteri and others which descend on the vagina; the latter anastomose with branches of the vaginal arteries and form with them two median longitudinal vessels—the *azygos arteries of the vagina*—one of which descends in front of, and the other behind, the vagina. It supplies numerous branches to the body of the uterus, and from its terminal portion twigs are distributed

to the uterine tube and the round ligament of the uterus. The terminal branches in the uterine muscle are exceedingly tortuous.

The **vaginal artery**, frequently represented by two or three branches, usually corresponds to the inferior vesical in the male; it descends upon the vagina, supplying its mucous membrane, and sends branches to the bulb of the vestibule, the

FIG. 731.—A dissection of the pelvic contents from the left side.



Note.—Most of the left hip-bone has been removed together with the Obturator internus muscle. The Sciatic nerve has been cut away close to its origin from the sacral plexus.

All the vessels and nerves exposed are those of the left side.

fundus of the bladder and the contiguous part of the rectum. It assists in forming the azygos arteries of the vagina, which run longitudinally down the front and back of that organ.

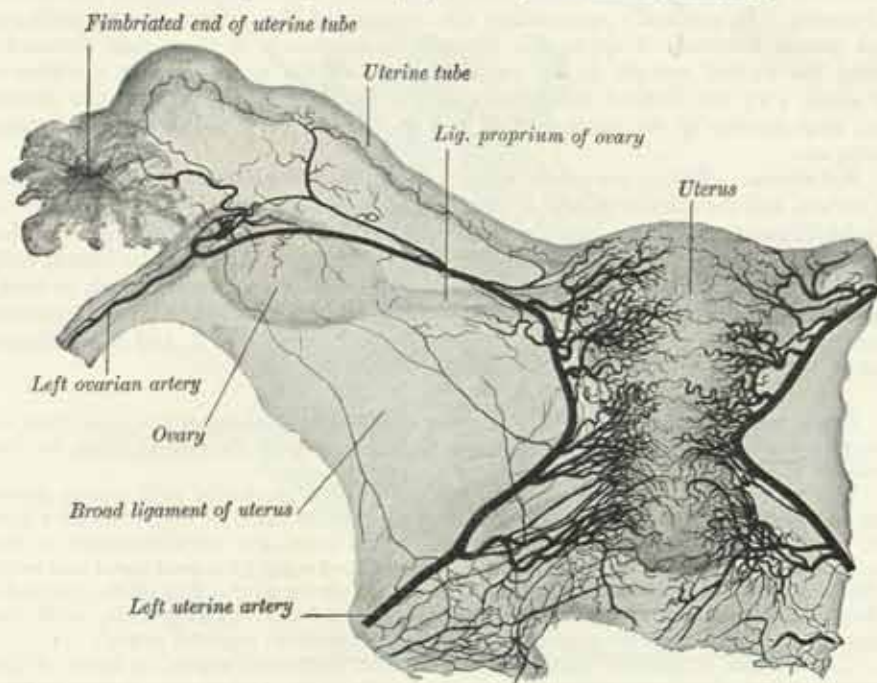
The **obturator artery** (fig. 730) passes forwards and downwards on the lateral wall of the pelvis, to the upper part of the obturator foramen, and, escaping from the pelvic cavity through the obturator canal, divides into an anterior and a posterior branch. In the pelvic cavity this vessel is in relation, laterally, with the obturator fascia, which separates it from the Obturator internus muscle; medially, it is

crossed by the ureter and the ductus deferens, which separate it from the parietal pelvic peritoneum; in the nullipara the ovary is a medial relation. The obturator nerve is above the vessel, and the obturator vein below it.

Branches.—*Inside the pelvis*, the obturator artery gives off (a) **iliac branches** to the iliac fossa; these supply the bone and the Iliacus, and anastomose with the iliolumbar artery; (b) a **vesical branch** which runs medially to the bladder, and may replace the inferior vesical branch of the internal iliac artery; and (c) a **pubic branch** which springs from the vessel just before it leaves the pelvic cavity; this branch ascends upon the back of the pubis and anastomoses with the corresponding vessel of the opposite side, and with the pubic branch of the inferior epigastric artery.

Outside the pelvis, the obturator artery divides, at the upper margin of the obturator foramen into an anterior and a posterior branch, which encircle the foramen under cover of the Obturator externus.

FIG. 732.—The left uterine and ovarian arteries of an unmarried girl aged 17½ years. Posterior aspect. (From a preparation by Hamilton Drummond.)



The **anterior branch** runs forwards on the outer surface of the obturator membrane and then curves downwards along the anterior margin of the foramen. It supplies branches to the Obturator externus, Pectineus, Adductores and Gracilis, and anastomoses with the posterior branch and with the medial circumflex femoral artery.

The **posterior branch** follows the posterior margin of the foramen and turns forwards on the ramus of the ischium where it anastomoses with the anterior branch. It gives twigs to the muscles attached to the ischial tuberosity and anastomoses with the inferior gluteal artery. It also supplies an **acetabular branch** which enters the hip-joint through the acetabular notch, ramifies in the fat of the acetabular fossa, and sends a twig along the ligamentum capitis femoris to the head of the femur.

Peculiarities.—In about 28 per cent. of subjects the place of the obturator artery is taken by an enlarged pubic branch of the inferior epigastric artery (p. 817); this branch descends almost vertically to the upper part of the obturator foramen. The artery usually lies in contact with the external iliac vein, and on the lateral side of the femoral ring; in such cases it would not be endangered in the operation for strangulated femoral hernia. Occasionally, however, it curves along the free margin of the lacunar ligament, and if in such circumstances a femoral hernia occurred, the vessel would almost completely encircle, and might constrict, the neck of the hernial sac; moreover, it would be in great danger of being wounded if an operation were

performed for strangulation. The obturator artery sometimes arises from the main stem or from the posterior trunk of the internal iliac artery, or it may spring from the superior gluteal artery: occasionally it arises from the external iliac artery.

The **internal pudendal artery** (figs. 730, 731, 733, 734), the smaller of the two terminal branches of the anterior trunk of the internal iliac artery, supplies the external organs of generation. Though the course of the artery is the same in the two sexes, the vessel is smaller in the female than in the male, and the distribution of its branches somewhat different.

The **internal pudendal artery in the male** runs downwards and laterally to the lower border of the greater sciatic foramen, and, passing from the pelvis between the Piriformis and Coccygeus, enters the gluteal region through the lower part of the greater sciatic foramen; it then crosses the back of the tip of the ischial spine, and enters the perineum through the lesser sciatic foramen. The artery then traverses the pudendal canal in the lateral wall of the ischiorectal fossa, and so crosses the Obturator internus, being situated about 4 cm. above the lower margin of the ischial tuberosity. It gradually approaches the margin of the ramus of the ischium and passes forwards deep to the perineal membrane; it then runs forwards along the medial margin of the inferior ramus of the pubis, and at a distance of about 1.25 cm. behind the inferior pubic ligament it divides into the *dorsal* and *deep arteries of the penis*, but it may pierce the perineal membrane before doing so.

Relations.—Within the pelvis, it lies in front of the Piriformis, the sacral plexus of nerves, and the inferior gluteal artery. As it crosses the ischial spine, it is covered by the Gluteus maximus; here the pudendal nerve lies medial, and the nerve to the Obturator internus lateral, to the vessel. In the perineum it lies on the lateral wall of the ischiorectal fossa in the pudendal canal (p. 603); it is accompanied, at first, by a pair of *venæ comitantes* and by the pudendal nerve and then by its terminal branches, viz. the dorsal nerve of the penis, which lies above it, and the perineal nerve, which lies below it.

Branches (figs. 733, 734).—The **muscular branches** consist of two sets; one to the muscles in the pelvis; the other, as the vessel crosses the ischial spine, to the muscles of the gluteal region.

The **inferior rectal artery** arises from the internal pudendal as it passes above the ischial tuberosity. Piercing the wall of the pudendal canal (p. 603) it divides into two or three branches which cross the ischiorectal fossa, and are distributed to the muscles and skin of the anal region. In addition they supply the anal canal and send offshoots round the lower edge of the Gluteus maximus to the skin of the buttock. They anastomose with the corresponding vessels of the opposite side, with the superior and middle rectal arteries, and with the transverse perineal artery.

The **scrotal branches** arise from the internal pudendal artery, in front of the preceding branches, cross either superficial, or deep to the Transversus perinei superficialis, and run forwards in the interspace between the Bulbospongiosus and Ischio-cavernosus, to both of which they supply branches, and finally are distributed to the skin and Dartos muscle of the scrotum. They often spring from the succeeding artery.

The **transverse perineal artery** arises from the internal pudendal artery, just before it passes deep to the perineal membrane. It runs transversely on the superficial surface of the Transversus perinei superficialis, and anastomoses with the corresponding vessel of the opposite side and with the scrotal and inferior rectal arteries. It supplies the Transversus perinei superficialis and the structures between the anus and the bulb of the penis.

The **artery of the bulb of the penis** is a short vessel of relatively large calibre which arises from the internal pudendal artery as it lies deep to the perineal membrane; it passes medially, pierces the membrane, and gives off branches which ramify in the bulb of the penis and in the posterior part of the corpus spongiosum penis. It supplies a small branch to the bulbo-urethral gland.

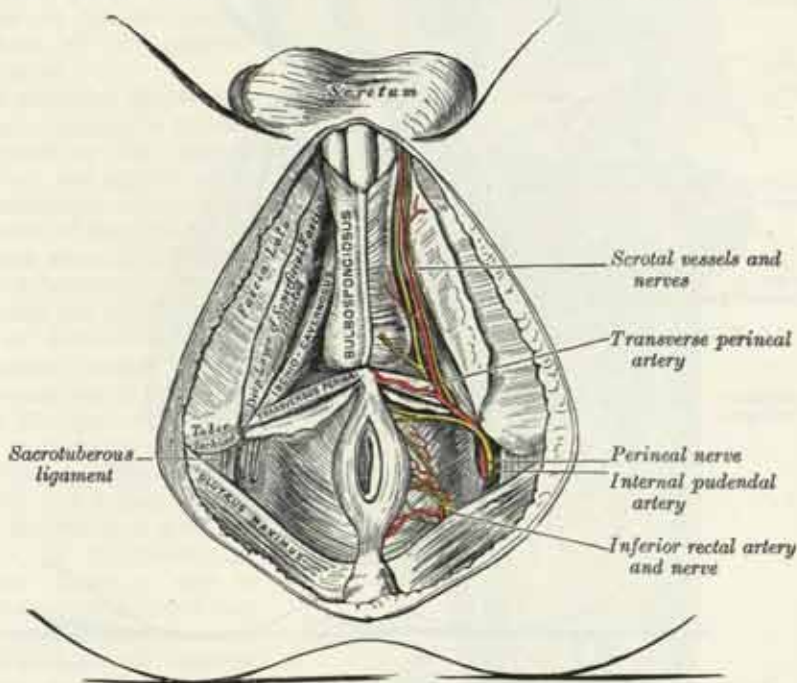
The **urethral artery** arises a short distance in front of the artery of the bulb. It runs forwards and medially, pierces the perineal membrane and enters the corpus spongiosum penis, in which it is continued forwards to the glans penis.

The **deep artery of the penis**, one of the terminal branches of the internal pudendal artery, arises from that vessel while it is situated deep to the perineal membrane; it pierces the membrane, and, entering the crus penis obliquely, runs forwards in the centre of the corpus cavernosum penis, and supplies its erectile tissue.

The **dorsal artery of the penis** pierces the perineal membrane, and ascends between the crus penis and the pubic symphysis. It then passes between the two layers of the suspensory ligament of the penis, and runs forwards on the dorsum of the penis to the glans, where it divides into two branches, which supply the glans and prepuce. On the penis, it lies between the dorsal nerve and deep dorsal vein, the former being on its lateral side. It supplies the skin and the fibrous sheath of the corpus cavernosum penis, sending branches through the sheath to anastomose with the deep artery of the penis.

The **internal pudendal artery in the female** is smaller than in the male. Its origin and course are similar, and there is considerable analogy in the distribution of its branches. The labial branches supply the labia pudendi; the artery of the bulb is distributed to the bulb of the vestibule and the erectile tissue of the vagina; the deep artery of the clitoris supplies the corpus cavernosum clitoridis; the dorsal

FIG. 733.—The superficial branches of the internal pudendal artery, in the male.



artery of the clitoris gives branches to the dorsum of that organ, and ends in the glans and prepuce of the clitoris.

Peculiarities.—Occasionally some of the branches of the internal pudendal are supplied by an additional vessel called the *accessory pudendal*, which generally arises from the internal pudendal artery before its exit from the greater sciatic foramen.

The **inferior gluteal artery** (figs. 731, 735), the larger of the two terminal branches of the anterior trunk of the internal iliac artery, is distributed chiefly to the buttock and the back of the thigh. It runs down on the sacral plexus of nerves and the Piriformis, behind the internal pudendal artery, and, passing between the first and second, or second and third, sacral nerves, and then between the Piriformis and Coccygeus it reaches the lower part of the greater sciatic foramen, through which it leaves the pelvis to gain the gluteal region. It then descends in the interval between the greater trochanter of the femur and the tuberosity of the ischium, accompanied by the sciatic and posterior femoral cutaneous nerves, and covered by the Gluteus maximus; it is continued down the back of the thigh, supplying the skin, and anastomosing with branches of the perforating arteries.

Surface Anatomy.—The inferior gluteal artery leaves the pelvis at about the mid-point of a line joining the posterior superior iliac spine and the ischial tuberosity.

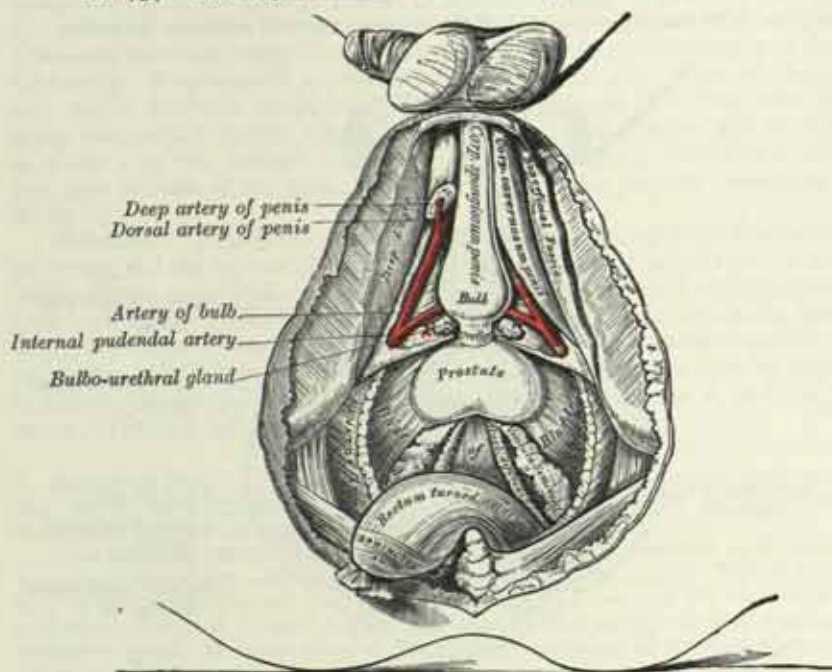
Branches.—*Inside the pelvis.* It distributes (a) branches to the Piriformis, Coccygeus and Levator ani; (b) branches which supply the fat around the rectum, and occasionally take the place of the middle rectal artery; and (c) vesical branches to the fundus of the bladder, seminal vesicles and prostate.

Outside the pelvis.—**Muscular branches** supply the Gluteus maximus, the lateral rotators of the thigh, and the muscles attached to the tuberosity of the ischium; they anastomose with the superior gluteal, internal pudendal, obturator and medial circumflex femoral arteries.

Coccygeal branches run medially, pierce the sacrotuberous ligament, and supply the Gluteus maximus and the structures on the back of the coccyx.

The **arteria comitans nervi ischiadici**, a long slender vessel, accompanies the sciatic nerve for a short distance; it then penetrates it, and runs in its substance to the lower part of the thigh.

FIG. 734.—The deeper branches of the internal pudendal artery, in the male.



An **anastomotic branch**, directed obliquely downwards across the lateral rotator muscles of the thigh, assists in forming the so-called *cruciate anastomosis* (p. 824) by joining with the first perforating and the medial and lateral circumflex femoral arteries.

An **articular branch**, generally derived from the anastomotic, is distributed to the capsule of the hip-joint.

Cutaneous branches are distributed to the skin of the buttock and back of the thigh.

Branches from the posterior trunk of the internal iliac artery.—The **ilio-lumbar artery** (fig. 730), runs upwards and laterally, in front of the sacro-iliac joint and the lumbosacral trunk, and behind the obturator nerve and the external iliac vessels, to the medial border of the Psoas major, behind which it divides into a lumbar and an iliac branch.

The **lumbar branch** supplies the Psoas major and Quadratus lumborum, anastomoses with the fourth lumbar artery, and sends a small *spinal branch* through the intervertebral foramen between the fifth lumbar vertebra and the base of the sacrum, into the vertebral canal to supply the cauda equina.

The **iliac branch** supplies the Iliacus; some offsets run between the muscle and the bone, and anastomose with the iliac branches of the obturator artery; one of these enters an oblique canal to supply the bone, while others run along the crest of the ilium, distributing branches to the gluteal and abdominal muscles, and anastomosing in their course with the superior gluteal, circumflex iliac and lateral circumflex femoral arteries.

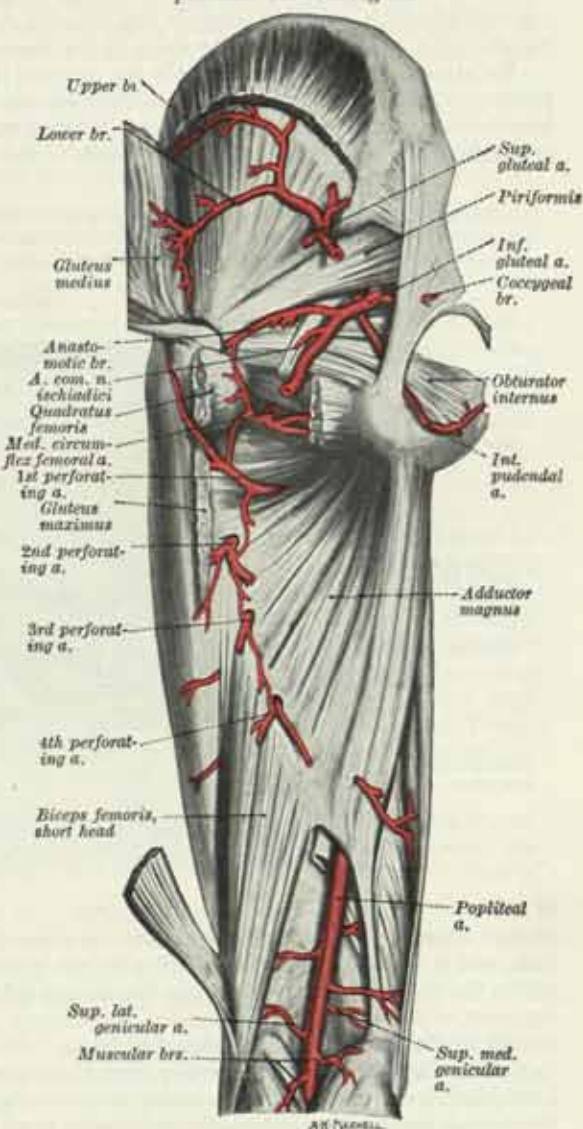
The **lateral sacral arteries** (fig. 730) arise from the posterior trunk of the internal iliac artery; there are usually two, a superior and an inferior. The *superior*, and larger, passes medially, and enters the first or second pelvic sacral foramen, supplying branches to the contents of the sacral canal, and, escaping by the corresponding dorsal sacral foramen, is distributed to the skin and muscles on the dorsum of the sacrum, anastomosing with the superior gluteal artery. The *inferior* runs obliquely across the front of the Piriformis and the sacral nerves, descends on the front of the sacrum lateral to the sympathetic trunk, and anastomoses over the coccyx with the median sacral artery and the opposite lateral sacral artery. Branches from this vessel enter the pelvic sacral foramina to be distributed like those of the superior lateral sacral.

The **superior gluteal artery** (figs. 730, 735) is the largest branch of the internal iliac artery, and appears to be the continuation of the posterior trunk of that vessel. It is a short artery which runs backwards between the lumbosacral trunk and the first sacral nerve, or between the first and second sacral nerves, and, passing out of the pelvis through the upper part of the greater sciatic foramen above the piriformis, divides into a *superficial* and a *deep* branch. Within the pelvis it gives off twigs to the Piriformis and Obturator internus, and a nutrient artery to the hip-bone.

The *superficial branch* enters the deep surface of the Gluteus maximus, and divides into numerous branches; some of these supply the muscle and anastomose with the inferior gluteal artery; others perforate the tendinous origin of the muscle, supply the skin covering the posterior surface of the sacrum, and anastomose with the posterior branches of the lateral sacral arteries.

The *deep branch* lies under the Gluteus medius and soon splits into a superior and an inferior division. The *superior division* runs along the upper border of the Gluteus minimus to the anterior superior iliac spine, anastomosing with the deep circumflex iliac artery and the ascending branch of the lateral circumflex femoral artery. The *inferior division* crosses the Gluteus minimus obliquely, distributes branches to this muscle and to the Gluteus medius, and anastomoses with the lateral circumflex femoral artery; one branch enters the trochanteric fossa, where it anastomoses with the inferior gluteal and the ascending branch of the medial circumflex femoral artery; other branches pierce the Gluteus minimus and supply the hip-joint.

FIG. 735.—The arteries of the left gluteal and posterior femoral region.



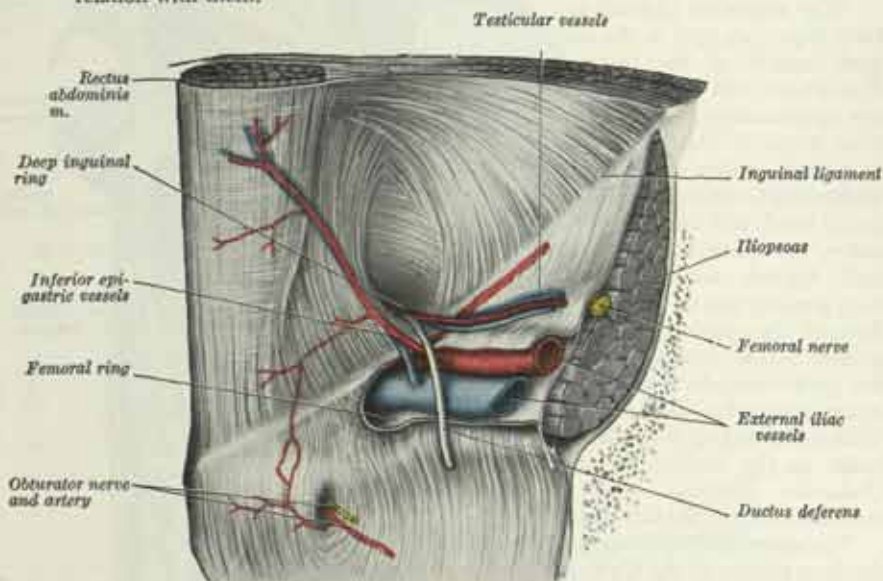
Surface Anatomy.—The superior gluteal artery emerges from the pelvis at the junction of the upper and middle thirds of a line joining the posterior superior iliac spine to the apex of the greater trochanter of the femur.

THE EXTERNAL ILIAC ARTERY (figs. 730, 736)

The **external iliac artery** is larger than the internal iliac artery, and runs obliquely downwards and laterally, along the medial border of the Psoas major. It extends from the bifurcation of the common iliac artery to a point behind the inguinal ligament, midway between the anterior superior iliac spine and the symphysis pubis, where it enters the thigh as the femoral artery.

Relations.—*In front and medially* the external iliac artery is in relation with the peritoneum and extraperitoneal tissue, which separate the right artery from the termination of the ileum and frequently the vermiform appendix, and the left artery from the sigmoid colon and some coils of the small intestine. The beginning

FIG. 736.—A dissection of the deep surface of the lower part of the abdominal wall of the right side below the level of the arcuate line. The femoral and deep inguinal rings are displayed, together with the vessels and other structures in relation with them.



of the artery may be crossed by the ureter; in the female it is crossed by the ovarian vessels. The testicular vessels lie for some distance upon it near its termination, and it is crossed in this situation by the genital branch of the genitofemoral nerve, the deep circumflex iliac vein, the ductus deferens in the male, and the round ligament of the uterus in the female. *Posteriorly* it is separated from the medial border of the Psoas major by the iliac fascia. The external iliac vein lies partly behind the upper part of the artery, but is on the medial side of its lower part. *Laterally* it is related to the Psoas major, from which it is separated by the iliac fascia. Numerous lymphatic vessels and lymph nodes lie on the front and sides of the vessel.

Branches.—Besides supplying several small branches to the Psoas major and the neighbouring lymph nodes, the external iliac artery gives off the inferior epigastric and deep circumflex iliac branches.

The **inferior epigastric artery** (figs. 587, 736) arises from the external iliac artery immediately above the inguinal ligament. It curves forwards in the extraperitoneal tissue, and then ascends obliquely along the medial margin of the deep inguinal ring; continuing its upward course, it pierces the transversalis fascia, passes in front of the arcuate line, and ascends between the Rectus abdominis and the posterior lamella of its sheath. It finally divides into numerous branches, which anastomose, above the umbilicus, with the superior epigastric branch of the internal thoracic artery and with the lower posterior intercostal arteries. As the inferior

epigastric artery passes obliquely upwards from its origin it lies along the lower and medial margins of the deep inguinal ring, and behind the commencement of the spermatic cord, separated from it by the transversalis fascia. In the male the ductus deferens, and in the female the round ligament of the uterus, winds round its lateral surface. The inferior epigastric artery supplies the following branches:

The **cremasteric artery** accompanies the spermatic cord, supplies the Cremaster and other coverings of the cord, and anastomoses with the testicular artery. In the female the artery is very small and accompanies the round ligament of the uterus.

A **pubic branch** descends along the medial margin of the femoral ring to the back of the pubis, and there anastomoses with the pubic branch of the obturator artery. In about 28 per cent. of subjects the pubic branch is large, and takes the place of the obturator artery (p. 811).

Branches are distributed to the abdominal muscles and the peritoneum, and anastomose with the circumflex iliac and lumbar arteries.

Cutaneous branches perforate the aponeurosis of the External oblique muscle, supply the skin and anastomose with branches of the superficial epigastric artery.

Peculiarities.—The inferior epigastric artery may arise below the inguinal ligament, from the femoral artery and then it ascends in front of the femoral vein. It frequently springs from the external iliac artery, by a common trunk with the abnormal obturator artery and rarely it arises from the obturator artery.

Applied Anatomy.—The inferior epigastric artery has important surgical relations, and is one of the principal means, through its anastomosis with the internal thoracic, of establishing the collateral circulation after ligature of either the common or external iliac arteries. It lies close to the deep inguinal ring, and is therefore *medial* to the neck of the sac of an oblique inguinal hernia, but *lateral* to that of a direct inguinal hernia, as these emerge from the abdomen.

The **deep circumflex iliac artery** arises from the lateral side of the external iliac artery nearly opposite the inferior epigastric artery. It ascends obliquely to the anterior superior iliac spine and behind the inguinal ligament, in a sheath formed by the junction of the transversalis and iliac fasciae. There it anastomoses with the ascending branch of the lateral circumflex femoral artery. It then pierces the transversalis fascia and passes along the inner lip of the crest of the ilium to about its middle, where it perforates the Transversus abdominis and runs backwards between that muscle and the Internal oblique, to anastomose with the ilio-lumbar and superior gluteal arteries. Opposite the anterior superior iliac spine it gives off a large *ascending branch* (fig. 585), which runs between the Internal oblique and Transversus, supplying them, and anastomosing with the lumbar and inferior epigastric arteries.

Collateral Circulation.—A collateral circulation is fairly quickly established after ligature of the common iliac artery in young adults.* When the arterial walls are degenerated in older subjects, however, it is unlikely to be efficient enough to supply the limb.

THE ARTERIES OF THE LOWER LIMB

The chief artery of the lower limb is a direct continuation of the external iliac. It extends from the level of the inguinal ligament to the lower border of the Popliteus, where it divides into the anterior and posterior tibial arteries. Its upper part is named the femoral artery; its lower, the popliteal artery.

THE FEMORAL ARTERY (figs. 737-741)

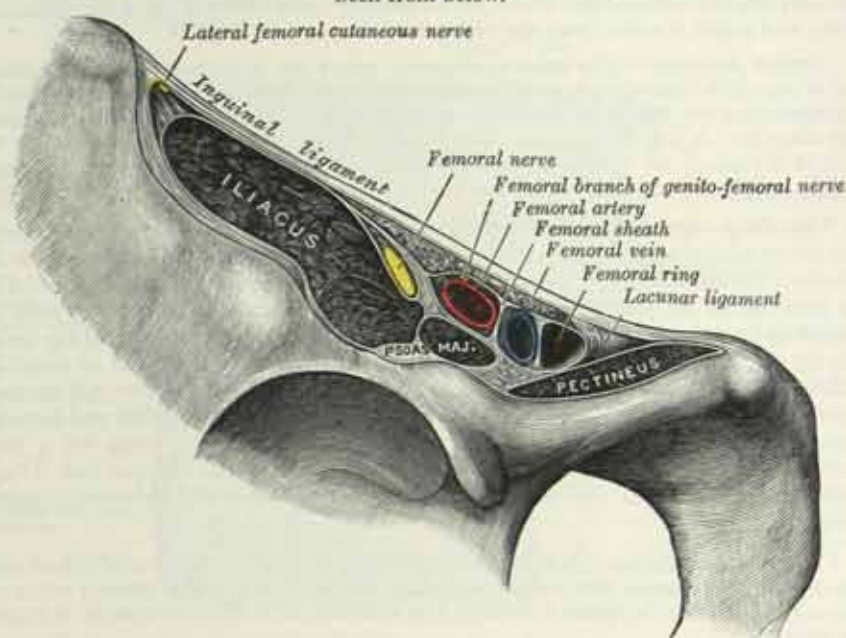
The **femoral artery** is the continuation of the external iliac artery. It begins behind the inguinal ligament, midway between the anterior superior iliac spine and the symphysis pubis, and passes down the front and medial side of the thigh. It ends at the junction of the middle with the lower one-third of the thigh, where it passes through an opening in the Adductor magnus to become the popliteal artery.

* For details see papers by Owen, *Med. Chir. Trans.* vol. xvi and Sir Astley Cooper, *Guy's Hospital Reports*, vol. i.

The upper part of the femoral artery is contained in the *femoral triangle*, the lower part in the *adductor (subsartorial) canal*. The first 3 cm. or 4 cm. of the vessel are enclosed, together with the femoral vein, in the *femoral sheath*.

The **femoral sheath** (fig. 737) is formed by a prolongation downwards, behind the inguinal ligament, of the fasciæ lining the abdomen, the transversalis fascia being continued down in front of the femoral vessels and the iliopectineal fascia behind them. The sheath has the form of a short funnel, the wide end of which is directed upwards, while the lower, narrow end fuses with the fascial investment of the vessels, about 3 or 4 cm. below the inguinal ligament. In the newly-born the sheath is much shorter and becomes elongated after birth when the extended position of the thigh becomes habitual. The lateral wall of the sheath is vertical and is perforated by the femoral branch of the genitofemoral nerve; the medial wall is directed obliquely downwards and laterally, and is pierced by the long saphenous vein and by some lymphatic vessels. Like the carotid sheath (p. 566) in structure, the femoral sheath consists of a mass of connective tissue in which the

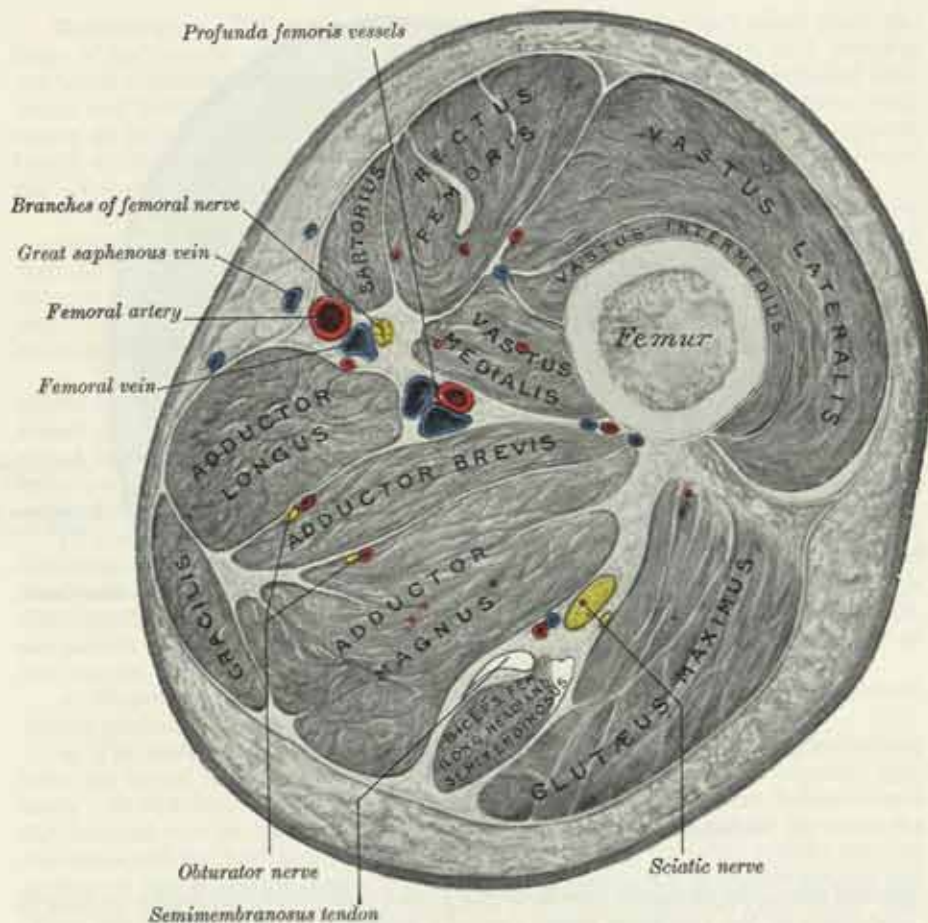
FIG. 737.—The structures passing behind the inguinal ligament.
Seen from below.



femoral vessels are imbedded. It is customary to describe three compartments; of these, the lateral contains the femoral artery, the intermediate the femoral vein, while the medial and smallest compartment is named the *femoral canal*, and contains some lymph vessels and a lymph node, imbedded in a small amount of areolar tissue. The femoral canal is conical and measures 1.25 cm. in length; its base, directed upwards and named the *femoral ring*, is oval in form, its long or transverse diameter measuring 1.25 cm. The femoral ring (fig. 737) is bounded in front by the inguinal ligament, behind by the Pectineus covered by its fascia, medially by the crescentic base of the lacunar ligament, and laterally by the femoral vein. The spermatic cord in the male, and the round ligament of the uterus in the female, lie immediately above the anterior margin of the ring, while the inferior epigastric vessels are close to the junction of its anterior and lateral boundaries. The ring is larger in women than in men. This difference is accounted for partly by the greater breadth of the female pelvis and partly by the smaller size of the femoral vessels. The femoral ring is closed by a somewhat condensed portion of the extraperitoneal tissue, named the *femoral septum*, which contains a small lymph node and is covered by the parietal layer of the peritoneum. The femoral septum is pierced by numerous lymph vessels passing from the deep inguinal to the external iliac lymph nodes.

The **femoral triangle** (fig. 622) corresponds to the depression seen immediately below the fold of the groin. Its apex is directed downwards, and the sides are formed, laterally by the medial margin of the Sartorius, medially by the medial margin of the Adductor longus, above by the inguinal ligament. The floor of the triangle is gutter-like and is formed laterally by the Iliacus and Psoas major, and medially by the Pectineus and Adductor longus. The femoral vessels, which extend from near the middle of its base to its apex, lie in the deepest part of the gutter. On the lateral side of the femoral artery the femoral nerve divides into its branches. Besides the vessels and nerves, this triangle contains some fat and lymph nodes.

FIG. 738.—A transverse section through the thigh at the level of the apex of the femoral triangle. About four-fifths of the natural size.



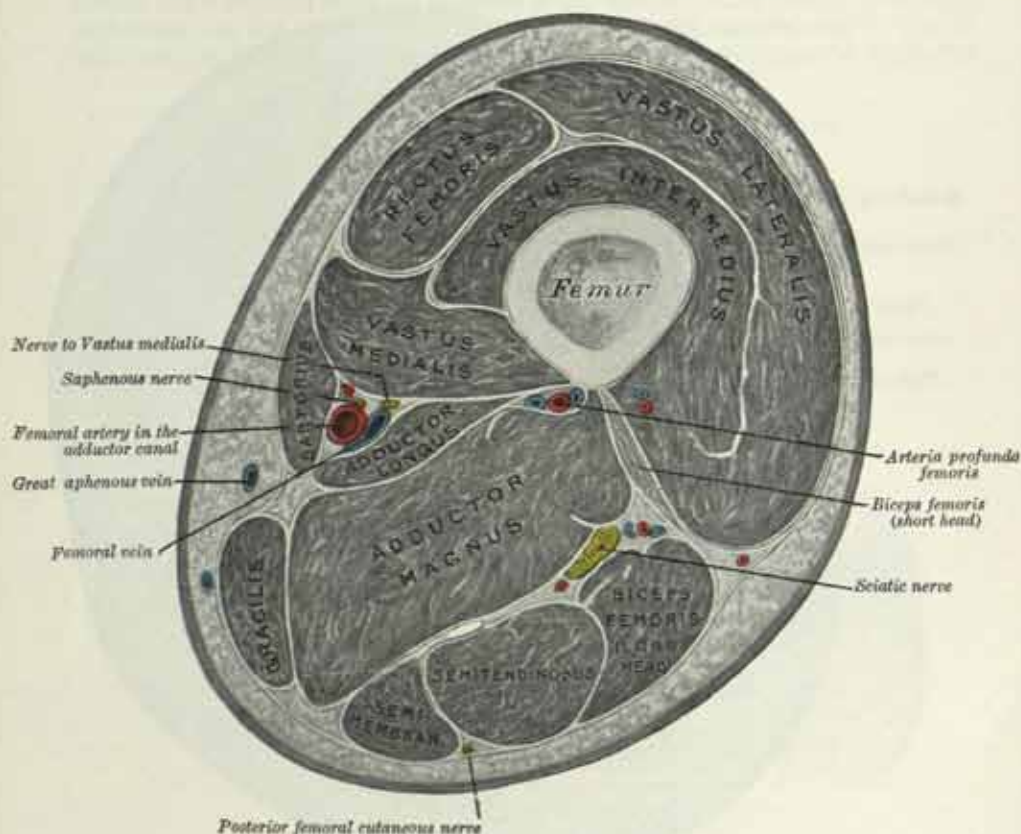
The **adductor (subsartorial) canal** (fig. 739) is an aponeurotic tunnel in the middle one-third of the thigh, extending from the apex of the femoral triangle to the opening in the Adductor magnus through which the femoral vessels pass from the front of the thigh to the popliteal fossa. It is triangular on transverse section, and is bounded, in front and laterally, by the Vastus medialis; behind, by the Adductor longus above, and Adductor magnus below; and is roofed by a strong aponeurosis which extends from these muscles, across the femoral vessels, to the Vastus medialis. The Sartorius lies on the aponeurotic roof. The canal contains the femoral artery and vein, and the saphenous nerve; the nerve to the Vastus medialis traverses the proximal part of the canal, and then enters its muscle.

The relations of the femoral artery.—In the *femoral triangle* (fig. 740) the artery is covered with the skin and superficial fascia, the superficial inguinal lymph nodes, the fascia lata and the anterior part of the femoral sheath, and is crossed by the superficial circumflex iliac vein, which runs in the superficial fascia. The

femoral branch of the genitofemoral nerve courses for a short distance within the lateral compartment of the femoral sheath, and lies at first lateral to and then in front of the artery. Near the apex of the femoral triangle the medial cutaneous nerve of the thigh crosses the artery from its lateral to its medial side.

Behind, the artery lies in contact with the posterior part of the femoral sheath, by which it is separated from the tendon of the Psoas major, the Pectineus and the Adductor longus, in that order from above downwards. The artery is separated from the capsule of the hip-joint by the tendon of the Psoas major, from the Pectineus by the femoral vein and profunda vessels, and from the Adductor longus by the

FIG. 739.—A transverse section through the middle of the thigh. Four-fifths of natural size.



femoral vein—the profunda vessels having passed posterior to the Adductor longus. The nerve to the Pectineus passes medially behind the upper end of the artery. *Laterally* the artery is related to the femoral nerve. The femoral vein is medial to the artery in the upper part of the femoral triangle, and posterior to the artery in the lower part.

In the *adductor canal* (figs. 739, 740, 741) the femoral artery is more deeply situated, being covered with the skin, the superficial and deep fasciæ, the Sartorius and the fibrous roof of the canal. The saphenous nerve is at first on the lateral side of the artery; it then lies in front of it, and below is placed on its medial side. Behind, the artery is related to the Adductor longus above, and Adductor magnus below; *anterolateral* to it are the Vastus medialis and the nerve to this muscle. The femoral vein lies posterior to the upper, and lateral to the lower, part of the artery.

Surface Anatomy.—The artery enters the thigh at a point in the fold of the groin midway between the anterior superior iliac spine and the pubic symphysis. It corresponds to the upper two-thirds of a line joining this point to the adductor tubercle when the thigh is somewhat flexed, abducted and rotated laterally. The pulsations of the upper part of the vessel are readily palpable.

Peculiarities.—In rare cases the femoral artery divides, below the origin of the *arteria profunda femoris*, into two trunks, which reunite near the opening in the *Adductor magnus*. Occasionally the femoral artery is absent, its place being supplied by the inferior gluteal artery, which accompanies the sciatic nerve to the popliteal fossa. This condition represents a persistence of the upper part of the original axis artery (p. 172) and in these cases the external iliac artery is small, and ends as the *arteria profunda femoris*.

Applied Anatomy.—Compression of the femoral artery is most effectually made immediately below the inguinal ligament. In this situation the artery is superficial, and is separated from the superior ramus of the pubis by the *Psoas major*; here digital compression will effectually control the circulation through it. The vessel may also be controlled in the middle third of the thigh by a tourniquet which presses the vessel against the medial side of the femur.

Branches.—1. The **superficial epigastric artery** (fig. 740) arises from the front of the femoral artery about 1 cm. below the inguinal ligament, and, piercing the femoral sheath and the cribriform fascia, ascends in front of the inguinal ligament, and between the two layers of the superficial fascia of the abdominal wall nearly as far as the umbilicus. It distributes branches to the superficial inguinal lymph nodes, the superficial fascia and the skin; it anastomoses with branches of the inferior epigastric artery, and with its fellow of the opposite side.

2. The **superficial circumflex iliac artery** (fig. 740), the smallest of the superficial branches of the femoral artery, arises close to the preceding vessel, and running laterally, parallel with the inguinal ligament, pierces the fascia lata near the anterior superior iliac spine; it gives branches to the skin, superficial fascia and superficial inguinal lymph nodes, and anastomoses with the deep circumflex iliac, the superior gluteal and the lateral circumflex femoral arteries.

3. The **superficial external pudendal artery** (fig. 740) arises from the medial side of the femoral artery, close to the preceding vessels. After piercing the femoral sheath and the cribriform fascia, it courses medially, across the spermatic cord (or round ligament of the uterus in the female), to be distributed to the skin on the lower part of the abdomen, the penis and scrotum in the male, and the labium majus in the female, anastomosing with branches of the internal pudendal artery.

4. The **deep external pudendal artery** (fig. 740) passes medially across the Pectineus and either in front of or behind the *Adductor longus*; it is covered by the fascia lata, which it pierces at the medial side of the thigh, and thereafter it is distributed, in the male, to the skin of the scrotum and perineum, in the female to the labium majus; its branches anastomose with the scrotal (or labial) branches of the internal pudendal artery.

5. **Muscular branches** are supplied by the femoral artery to the *Sartorius*, *Vastus medialis* and the *Adductor* muscles.

6. The **arteria profunda femoris** (figs. 739, 740 and 741) is a large vessel arising from the lateral side of the femoral artery, about 3.5 cm. below the inguinal ligament. At first lateral to the femoral artery, the profunda then runs behind it and the femoral vein to the medial side of the femur, where it passes between the Pectineus and the *Adductor longus* and then lies between the latter and the anterior surface of the *Adductor brevis*. It continues between the *Adductor longus* and *Adductor magnus* and ends by piercing the *Adductor magnus* to anastomose with the upper muscular branches of the popliteal artery. The terminal part of the profunda is sometimes named the *fourth perforating artery*.

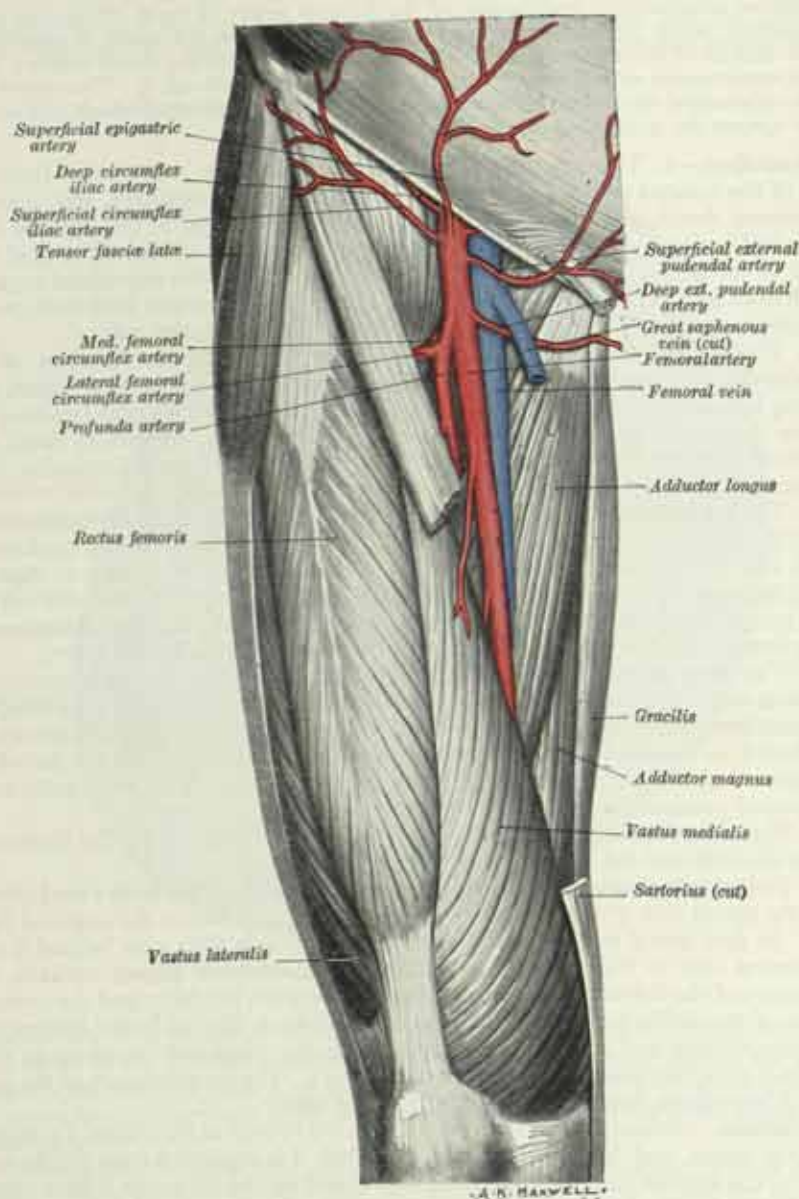
Relations.—*Behind*, from above downwards, it is related to the *Iliacus*, *Pectineus*, *Adductor brevis*, and *Adductor magnus*. *In front*, it is separated from the femoral artery by the femoral and profunda veins above, and by the *Adductor longus* below. *Laterally*, the origin of the *Vastus medialis* intervenes between it and the femur.

Peculiarities.—This vessel sometimes arises from the medial side, more rarely from the back of the femoral artery. When it arises from the medial side, it may cross in front of the femoral vein and then pass backwards round its medial side. The distance from the inguinal ligament of the origin of the vessel is variable. It is usually between 2.5 cms. and 5 cms. below it.

The *arteria profunda femoris* is the principal artery of supply to the adductor, extensor and hamstring muscles, and in addition it establishes a number of important anastomoses which serve to connect it with the internal and external iliac arteries above and the popliteal artery below (p. 824).

Branches.—The **lateral circumflex femoral artery** arises from the lateral side of the profunda artery, passes laterally between the divisions of the femoral nerve and behind the Sartorius and Rectus femoris, and divides into ascending, transverse and descending branches. Occasionally it arises from the femoral artery.

FIG. 740.—The right femoral vessels.



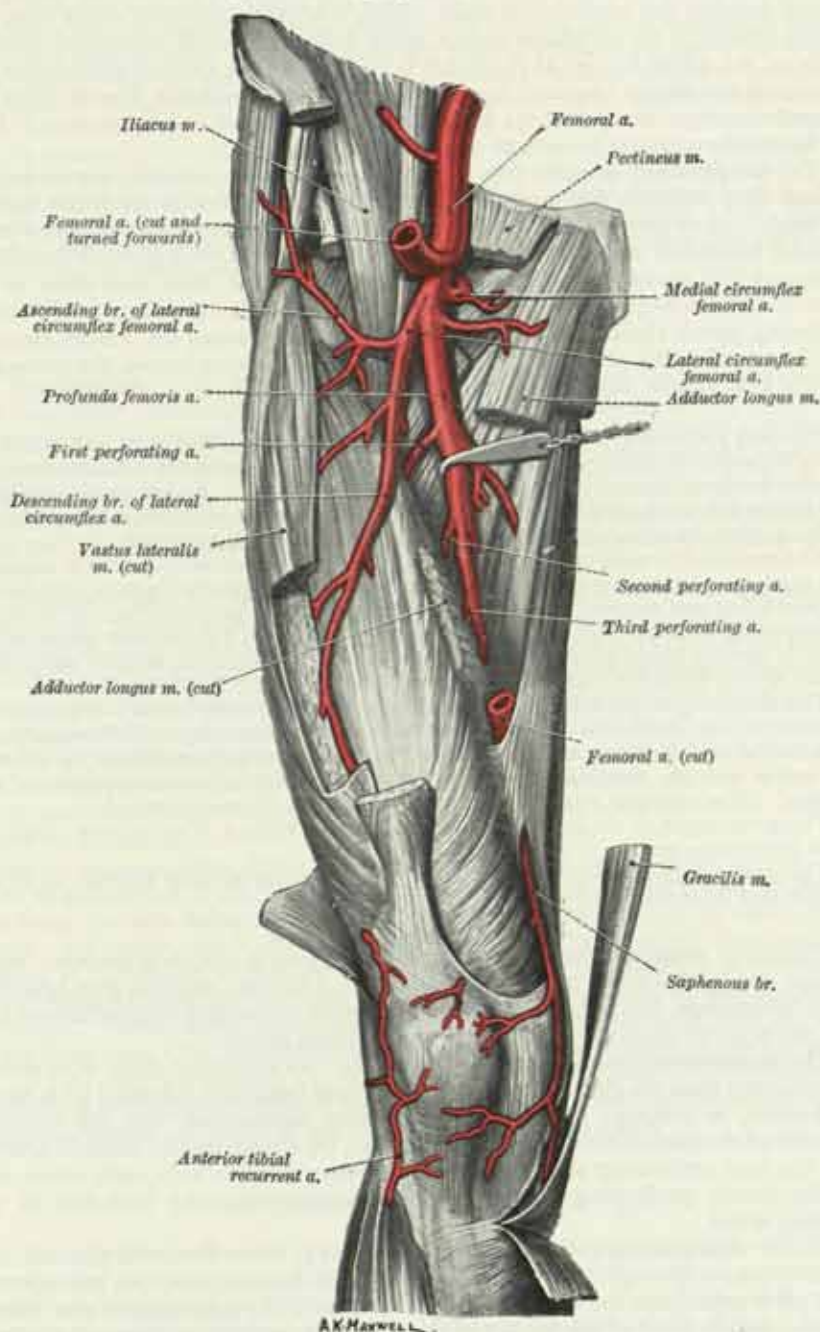
The *ascending branch* passes upwards along the intertrochanteric line, under cover of the Tensor fasciæ latæ, to the lateral part of the hip; it anastomoses with the terminal branches of the superior gluteal and deep circumflex iliac arteries, and sends a twig to the hip-joint between the medial and lateral parts of the ilio-femoral ligament.

The *descending branch*, which may arise as an independent branch direct from the profunda femoris or, sometimes, from the femoral artery, runs downwards, behind the Rectus femoris, along the anterior border of the Vastus lateralis, to which it gives offsets; one long branch descends in the latter muscle as far as the knee, and

anastomoses with the lateral superior genicular branch of the popliteal artery. It is accompanied by the nerve to the Vastus lateralis.

The *transverse branch*, the smallest, passes laterally over the Vastus intermedius, pierces the Vastus lateralis, and winds round the femur, just below the greater

FIG. 741.—The right profunda femoris artery.



trochanter, anastomosing on the back of the thigh with the medial circumflex femoral, inferior gluteal, and first perforating arteries (*cruciate anastomosis*).

The **medial circumflex femoral artery** usually arises from the posteromedial aspect of the profunda artery, but frequently springs from the femoral artery. It gives off *muscular branches* to the adductor muscles and then winds round the medial

side of the femur, passing first between the Pectineus and Psoas major, and then between the Obturator externus and Adductor brevis, and finally appears between the Quadratus femoris and the upper border of the Adductor magnus, where it divides into transverse and ascending branches. The *transverse branch* takes part in the formation of the cruciate anastomosis. The *ascending branch* runs obliquely upwards upon the tendon of the Obturator externus and in front of the Quadratus femoris towards the trochanteric fossa, where it anastomoses with twigs from the gluteal arteries. An *acetabular branch* arises from the medial circumflex femoral artery at the upper border of Adductor brevis and enters the hip-joint below the transverse acetabular ligament, in company with the acetabular branch from the obturator artery; it supplies the fat in the acetabular fossa, and is continued along the ligamentum capitis femoris to the head of the femur.

The **perforating arteries** (fig. 735), usually three in number, are so named because they perforate the insertion of the Adductor magnus to reach the back of the thigh. They pass backwards close to the linea aspera of the femur under cover of small tendinous arches in the insertion of the muscle, and give off muscular, cutaneous and anastomosing branches. Reduced in size, they pass deep to the short head of the Biceps femoris (the first usually pierces the insertion of the Gluteus maximus), pierce the lateral intermuscular septum and enter the Vastus lateralis. The first perforating artery is given off above the Adductor brevis, the second in front of that muscle, and the third immediately below it.

The *first perforating artery* passes backwards between the Pectineus and Adductor brevis (sometimes it perforates the latter muscle); it then pierces the Adductor magnus close to the linea aspera. It gives branches to the Adductor brevis, Adductor magnus, Biceps femoris and Gluteus maximus, and anastomoses with the inferior gluteal, medial and lateral circumflex femoral, and second perforating arteries.

The *second perforating artery*, larger than the first, but frequently arising in common with it, pierces the insertions of the Adductor brevis and Adductor magnus, and divides into ascending and descending branches, which supply the posterior femoral muscles, anastomosing with the first and third perforating arteries. The *nutrient artery* of the femur is usually given off from this artery; when two nutrient arteries exist, they usually spring from the first and third perforating vessels.

The *third perforating artery* is given off below the Adductor brevis; it pierces the insertion of the Adductor magnus, and divides into branches which supply the posterior femoral muscles, and anastomose above with the higher perforating arteries, and below with the termination of the profunda and the muscular branches of the popliteal. The nutrient artery of the femur may arise from this branch.

The termination of the profunda artery, already described, is sometimes called the *fourth perforating artery*.

The perforating arteries form a double chain of anastomosing vessels, (a) in the muscles and (b) close to the linea aspera.

Numerous **muscular branches** arise from the arteria profunda femoris; some of these end in the Adductors, others pierce the Adductor magnus, give branches to the hamstrings, and anastomose with the medial circumflex femoral artery and with the superior muscular branches of the popliteal artery.

The anastomosis on the back of the thigh.—An important chain of anastomoses stretches from the gluteal region to the popliteal fossa, and is formed from above downwards, as follows: (a) the gluteal arteries anastomose with the terminal branches of the medial circumflex femoral artery, (b) the circumflex femoral arteries with the first perforating artery, (c) the perforating arteries with each other, and (d) the fourth perforating artery with the superior muscular branches of the popliteal artery.

7. The **descending genicular artery** (fig. 744) arises from the femoral just before it passes through the opening in the Adductor magnus. It immediately gives off a saphenous branch, and then descends in the substance of the Vastus medialis, and in front of the tendon of the Adductor magnus, to the medial side of the knee, where it anastomoses with the medial superior genicular artery. It supplies *muscular branches* to the Vastus medialis and Adductor magnus, and gives off *articular branches*, which take part in the anastomosis round the knee-joint. One of the articular branches crosses above the patellar surface of the femur, forming an anastomotic arch with the lateral superior genicular artery, and supplying branches to the knee-joint.

The *saphenous branch* pierces the lower part of the roof of the adductor canal and accompanies the saphenous nerve to the medial side of the knee. It passes between the Sartorius and Gracilis, and is distributed to the skin of the upper and medial part of the leg, anastomosing with the medial inferior genicular artery.

Collateral Circulation.—After ligation of the femoral artery above the origin of the profunda femoris artery, the main channels for carrying on the circulation are the following anastomoses: (1) the superior and inferior gluteal branches of the internal iliac artery with the medial and lateral circumflex femoral and first perforating branches of the arteria profunda femoris; (2) the obturator branch of the internal iliac artery with the medial circumflex femoral of the arteria profunda femoris; (3) the internal pudendal branch of the internal iliac artery with the superficial and deep external pudendal branches of the femoral artery; (4) the deep circumflex iliac branch of the external iliac artery with the lateral circumflex femoral branch of the arteria profunda femoris and the superficial circumflex iliac branch of the femoral artery; and (5) the inferior gluteal branch of the internal iliac artery with the perforating branches of the arteria profunda femoris.

THE POPLITEAL FOSSA (figs. 637, 743, 981)

Boundaries.—The **popliteal fossa** is a lozenge-shaped space at the back of the knee-joint. Laterally, it is bounded by the Biceps femoris above, and by the Plantaris and the lateral head of the Gastrocnemius below; medially it is limited by the Semitendinosus and Semimembranosus above, and by the medial head of the Gastrocnemius below. The floor is formed by the popliteal surface of the femur, the oblique popliteal ligament of the knee-joint, the back of the upper end of the tibia and the fascia covering the Popliteus; the fossa is covered by the popliteal fascia.

Contents (figs. 743, 981).—When its boundaries are undisturbed, the popliteal fossa is only about 2.5 cm. wide, and very little can be seen of its contents. This is especially the case in the lower part of the space where the two heads of the Gastrocnemius lie in contact with each other. If, however, the boundaries be drawn apart the fossa is seen to contain the popliteal vessels, the tibial and the common peroneal (medial and lateral popliteal) nerves, the termination of the small saphenous vein, the lower part of the posterior femoral cutaneous nerve, the articular branch from the obturator nerve, a few small lymph nodes and a considerable quantity of fat. The tibial nerve descends through the middle of the fossa, lying under the popliteal fascia, and crossing the vessels posteriorly from the lateral to the medial side. The common peroneal nerve descends on the lateral side of the upper part of the fossa, close to the tendon of the Biceps femoris. The popliteal vessels are on the floor of the fossa, the vein being superficial to the artery and united to it by dense areolar tissue; the vein is a thick-walled vessel, and lies lateral to the artery above, and then crosses it posteriorly to gain its medial side below; sometimes it is double, the artery lying between the two veins, which are usually connected by short transverse branches. The articular branch from the obturator nerve descends upon the artery to the knee joint. The popliteal lymph nodes, six or seven in number, are embedded in the fat; one lies beneath the popliteal fascia near the termination of the small saphenous vein, another between the popliteal artery and the back of the knee-joint, while the others are placed at the sides of the popliteal vessels.

THE POPLITEAL ARTERY (figs. 742, 743)

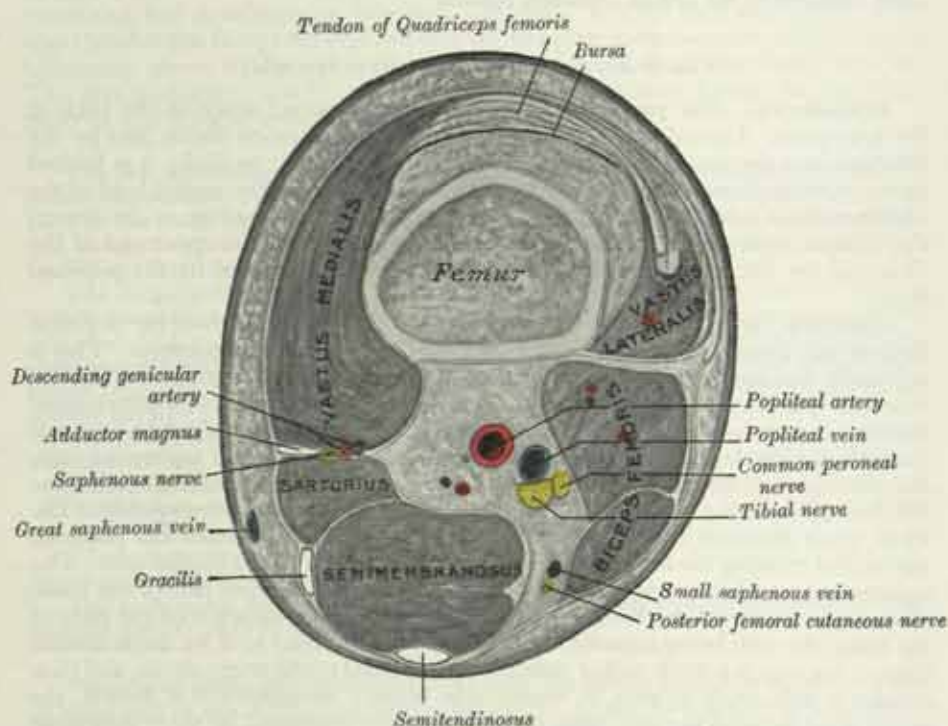
The **popliteal artery** is the continuation of the femoral artery, and courses through the popliteal fossa. It commences at the opening in the Adductor magnus, at the junction of the middle with the lower one-third of the thigh, and extends downwards and slightly laterally to the intercondylar fossa of the femur. It then runs vertically downwards to the lower border of the Popliteus, where it divides into *anterior and posterior tibial arteries*.

Relations.—In *front*, from above downwards, the artery lies on the fat covering the popliteal surface of the femur, the back of the knee-joint, and the fascia covering the Popliteus. *Behind*, it is overlapped by the Semimembranosus above, and is covered by the Gastrocnemius and Plantaris below. In the middle part

of its course the artery is separated from the skin and fasciæ by a quantity of fat, and is crossed from the lateral to the medial side by the tibial nerve and the popliteal vein, the vein being between the nerve and the artery and closely adherent to the latter. On its *lateral side*, above, are the Biceps femoris, the tibial nerve, the popliteal vein and the lateral condyle of the femur; below, the Plantaris and the lateral head of the Gastrocnemius. On its *medial side*, above, are the Semimembranosus and the medial condyle of the femur; below, the tibial nerve, the popliteal vein and the medial head of the Gastrocnemius. The relations of the popliteal lymph nodes to the artery are described above.

Peculiarities.—Occasionally the popliteal artery divides into its terminal branches opposite the knee-joint; when this occurs the anterior tibial artery usually descends

FIG. 742.—A transverse section through the thigh, 4 cm. above the adductor tubercle of the femur. Four-fifths of natural size.



in front of the Popliteus. The popliteal artery sometimes divides into the anterior tibial and peroneal arteries, the posterior tibial artery being wanting or rudimentary; occasionally it divides into three branches, the anterior and posterior tibial, and peroneal arteries.

Surface Anatomy.—The popliteal artery can be represented by a line which begins at the junction of the middle and lower thirds of the thigh 2.5 cm. medial to the middle line of the back of the limb, and runs downwards and laterally to reach the middle line at the level of the knee-joint. It then descends vertically to the level of the tibial tuberosity.

Branches.—The popliteal artery gives off cutaneous, muscular and genicular branches.

The **cutaneous branches** arise either from the popliteal artery or from some of its branches; they descend between the two heads of the Gastrocnemius, and, piercing the deep fascia, are distributed to the skin of the back of the leg; one usually accompanies the small saphenous vein.

The **superior muscular branches**, two or three in number, arise from the upper part of the artery, and pass to the Adductor magnus and the ham-

string muscles, anastomosing with the terminal part of the arteria profunda femoris.

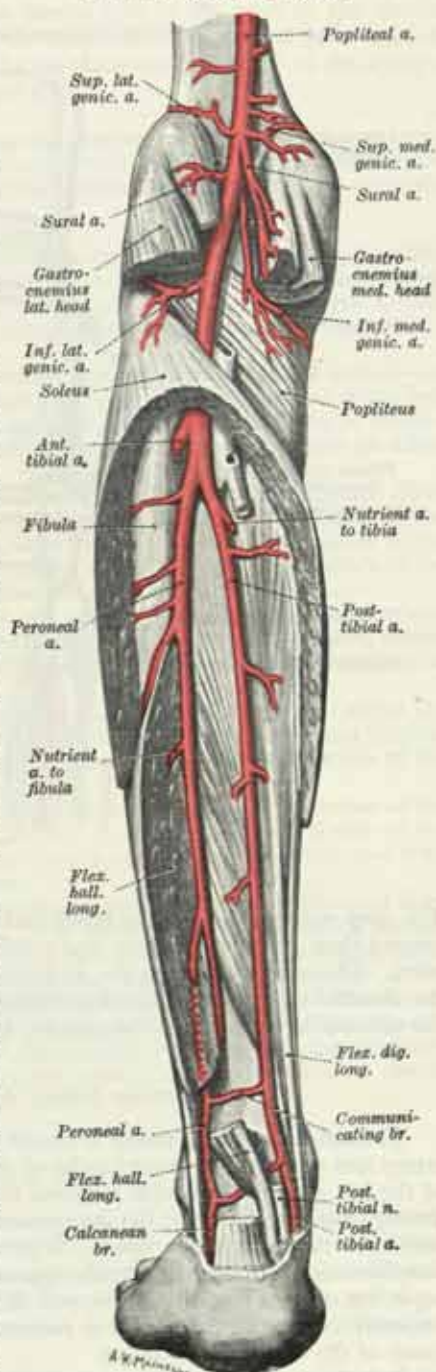
The **sural arteries** are two large branches which arise opposite the knee-joint and are distributed to the Gastrocnemius, Soleus and Plantaris.

The **superior genicular arteries** (figs. 743, 744), two in number, arise one from each side of the popliteal artery, and wind round the femur immediately above its condyles to gain the front of the knee-joint. The *medial superior genicular artery* runs under cover of the Semimembranosus and Semitendinosus, above the medial head of the Gastrocnemius, and passes deep to the tendon of the Adductor magnus. It divides into two branches, one of which supplies the Vastus medialis and anastomoses with the descending genicular and medial inferior genicular arteries; the other ramifies close to the surface of the femur and anastomoses with the lateral superior genicular artery. The size of the medial superior genicular artery varies inversely with that of the descending genicular. The *lateral superior genicular artery* passes under cover of the tendon of the Biceps femoris, and divides into a superficial and a deep branch; the superficial branch supplies the Vastus lateralis, and anastomoses with the descending branch of the lateral circumflex femoral artery and with the lateral inferior genicular artery; the deep branch anastomoses with the medial superior genicular artery, and forms an arch across the front of the femur with the descending genicular artery.

The **middle genicular artery**, a small branch, arises from the popliteal artery opposite the back of the knee-joint; it pierces the oblique popliteal ligament, and supplies the cruciate ligaments and the synovial membrane of the knee-joint.

The **inferior genicular arteries** (figs. 743, 744), two in number, arise from the popliteal artery under cover of the Gastrocnemius. The *medial inferior genicular artery* lies deep to the medial head of the Gastrocnemius and descends along the upper margin of the Popliteus, to which it gives branches; it then passes below the medial condyle of the tibia and under cover of the tibial collateral (medial) ligament of the knee; at the anterior border of this ligament it ascends to the front and medial side of the joint, supplies the joint and the upper end of the tibia, and anastomoses with the lateral inferior and medial superior genicular arteries. The *lateral inferior genicular artery* runs laterally across the Popliteus, and then forwards above the head of the fibula to the front of the knee joint, passing in its course under cover of the lateral head of the Gastrocnemius, the fibular collateral (lateral) ligament of the knee, and the tendon of the Biceps femoris. It divides into branches which anastomose with the medial inferior genicular, lateral superior genicular and anterior tibial recurrent arteries.

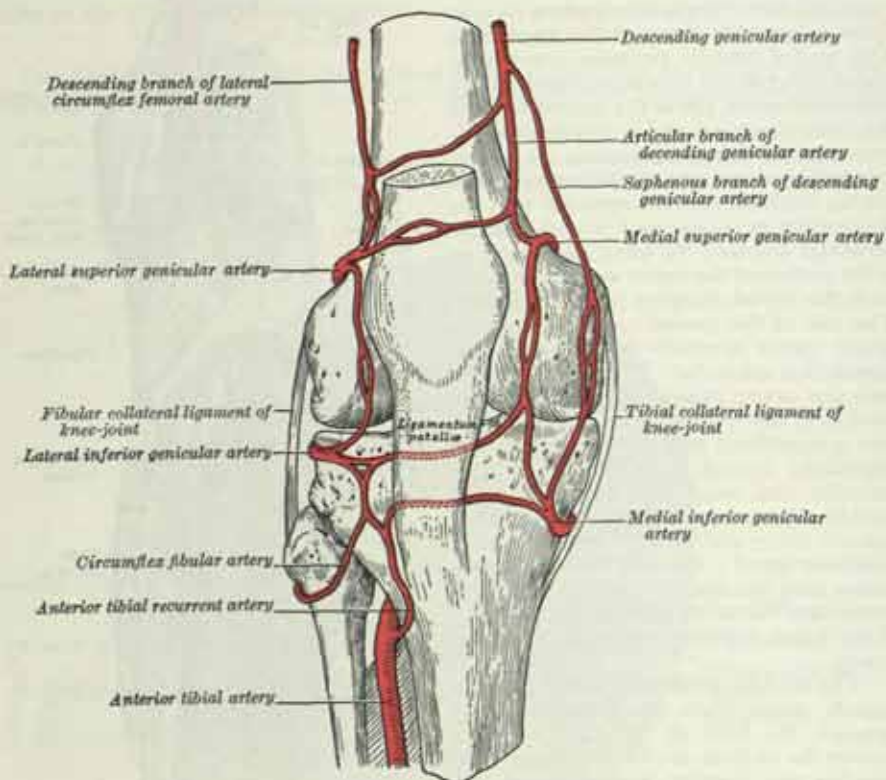
FIG. 743.—The left popliteal, posterior tibial and peroneal arteries.



The anastomosis around the knee-joint (fig. 744).—Around and above the

patella, and on the contiguous ends of the femur and tibia, an intricate arterial anastomosis forms a superficial and a deep network. The *superficial network* is situated between the fascia and skin round about the patella, and forms three well-defined arches; one above the patella in the loose connective tissue over the Quadriceps femoris, and two below the patella in the fat behind the ligamentum patellæ.

FIG. 744.—The arterial anastomosis around the knee-joint. (Schematic.)



The *deep network* lies on the lower end of the femur and upper end of the tibia around their articular surfaces, and sends numerous offsets into the interior of the joint. The vessels forming the anastomosis are the medial and lateral genicular, the descending genicular, the descending branch of the lateral circumflex femoral, the circumflex fibular, and the anterior tibial recurrent arteries.

THE ANTERIOR TIBIAL ARTERY (figs. 743, 745, 746)

The **anterior tibial artery** is one of the two terminal branches of the popliteal artery and arises at the lower border of the Popliteus. Situated at first on the back of the leg, it passes forwards between the two heads of the Tibialis posterior and through the upper part of the interosseous membrane to the front of the leg, lying medial to the neck of the fibula. It next descends on the anterior surface of the interosseous membrane, gradually approaching the tibia: at the lower part of the leg it lies on this bone (fig. 747), and then on the front of the ankle-joint midway between the two malleoli, and is continued on the dorsum of the foot under the name of the *dorsalis pedis* artery.

Relations.—In the upper two-thirds of its extent, the anterior tibial artery rests upon the interosseous membrane of the leg; in the lower one-third, upon the front of the tibia and the ankle-joint. In the upper one-third of its course, it lies between the Tibialis anterior and Extensor digitorum longus; in the middle one-third between the Tibialis anterior and Extensor hallucis longus. At the ankle it is crossed

from the lateral to the medial side by the tendon of the Extensor hallucis longus, and then lies between it and the first tendon of the Extensor digitorum longus. Its upper two-thirds are covered by the muscles which lie on each side of it, and by the deep fascia; its lower one-third, by the skin and fasciæ, and the extensor retinacula.

A pair of venæ comitantes lie one on each side of the artery. The deep peroneal (anterior tibial) nerve, coursing round the lateral side of the neck of the fibula, comes into relation with the lateral side of the artery shortly after the latter reaches the front of the leg; about the middle of the leg the nerve is in front of the artery; at the lower part it is generally on its lateral side.

Surface Anatomy.—The line representing the anterior tibial artery begins 2.5 cm. below the medial side of the head of the fibula and ends at the mid-point between the two malleoli. The vessel can be felt pulsating lateral to the tendon of the extensor hallucis longus at the ankle.

Peculiarities.—This vessel may be smaller than usual, or may be absent, its place being supplied by perforating branches from the posterior tibial, or by the perforating branch of the peroneal artery. The artery occasionally deviates towards the fibular side of the leg, regaining its usual position at the front of the ankle.

Branches.—The **posterior tibial recurrent artery**—an inconstant branch—is given off from the anterior tibial artery before that vessel reaches the front of the leg. It ascends in front of the Popliteus in company with the nerve to that muscle, anastomoses with the inferior genicular branches of the popliteal artery, and gives an offset to the superior tibiofibular joint.

The **anterior tibial recurrent artery** (fig. 745) arises from the anterior tibial artery, as soon as that vessel has reached the front of the limb; it ascends in the Tibialis anterior, ramifies on the front and sides of the knee-joint, and assists in the formation of the patellar network by anastomosing with the genicular branches of the popliteal artery, and with the descending genicular artery.

The **muscular branches** are numerous and are distributed to the muscles which lie on each side of the vessel; some pierce the deep fascia to supply the skin, others pass through the interosseous membrane of the leg, and anastomose with branches of the posterior tibial and peroneal arteries.

The **anterior medial malleolar artery** (fig. 745) arises about 5 cm. above the ankle-joint, and passes behind the tendons of the Extensor hallucis longus and Tibialis anterior, to the medial side of the ankle, where it anastomoses with branches of the posterior tibial and medial plantar arteries.

The **anterior lateral malleolar artery** (fig. 745) passes behind the tendons of the Extensor digitorum longus and Peroneus tertius; it supplies the lateral side of the ankle, and anastomoses with the perforating branch of the peroneal artery and with ascending twigs from the lateral tarsal artery.

The arteries around the ankle-joint anastomose freely with one another and form networks below the corresponding malleoli. The **medial malleolar network** is formed by the anterior medial malleolar branch of the anterior tibial artery, the medial tarsal branches of the dorsalis pedis artery, the malleolar and calcanean branches of the posterior tibial artery, and branches from the medial plantar artery. The **lateral malleolar network** is formed by the anterior lateral malleolar branch of the anterior tibial artery, the lateral tarsal branch of the dorsalis pedis artery, the perforating and the calcanean branches of the peroneal artery, and twigs from the lateral plantar artery.

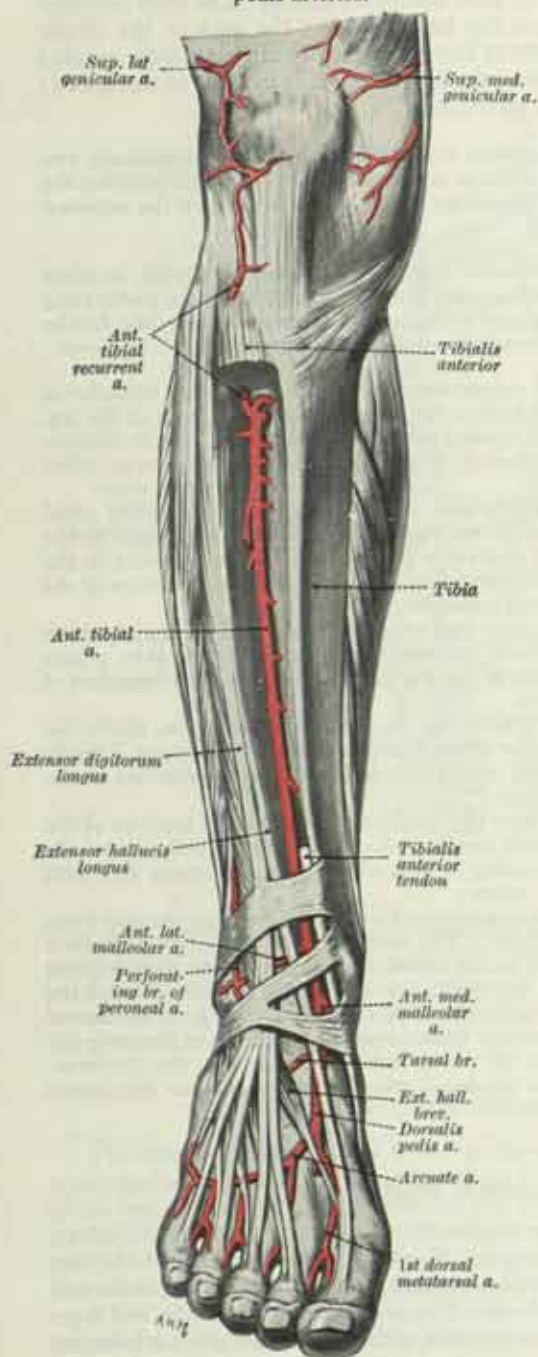
THE ARTERIA DORSALIS PEDIS (fig. 745)

The **arteria dorsalis pedis**, the continuation of the anterior tibial artery, passes distally from the ankle-joint along the tibial side of the dorsum of the foot to the proximal part of the first intermetatarsal space, where it descends into the sole of the foot between the two heads of the first Dorsal interosseous muscle, and completes the plantar arch (fig. 748). At its junction with this artery it gives off the **first plantar metatarsal artery** (p. 834).

Relations.—The **arteria dorsalis pedis** is accompanied by two veins, and lies successively upon the front of the articular capsule of the ankle-joint, the talus, navicular, and intermediate cuneiform bones, and the ligaments connecting them. It is covered by the skin, fasciæ, and inferior extensor retinaculum and crossed near its termination by the Extensor hallucis brevis. On its **tibial**

side it is related to the tendon of the Extensor hallucis longus; on its *fibular side*, to the first tendon of the Extensor digitorum longus, and the medial terminal branch of the deep peroneal (anterior tibial) nerve.

FIG. 745.—The right anterior tibial and dorsalis pedis arteries.



Note.—A large part of the tibialis anterior muscle has been excised in order to expose the anterior tibial artery in the leg.

plantar metatarsal arteries. The fourth dorsal metatarsal artery gives off a branch which supplies the lateral side of the fifth toe.

The first dorsal metatarsal artery arises from the dorsalis pedis artery just before

Surface Anatomy.—Being superficially placed, the vessel can be felt pulsating along a line from the midpoint between the two malleoli to the proximal end of the first intermetatarsal space.

Peculiarities.—The arteria dorsalis pedis may be larger than usual, to compensate for a small lateral plantar artery; or its place may be taken by a large perforating branch of the peroneal artery. It frequently curves laterally, lying lateral to the line between the middle of the ankle and the proximal part of the first interosseous space.

Branches.—The arteria dorsalis pedis gives off tarsal, arcuate and first dorsal metatarsal branches.

The **tarsal arteries**, lateral and medial (fig. 745), arise from the arteria dorsalis pedis as the latter crosses the navicular bone. The lateral branch passes laterally under cover of the Extensor digitorum brevis; it supplies this muscle and the articulations of the tarsus, and anastomoses with branches of the arcuate, anterior lateral malleolar, and lateral plantar arteries, and with the perforating branch of the peroneal artery.

The medial tarsal branches are two or three small vessels which ramify on the medial border of the foot and join the medial malleolar network.

The **arcuate artery** (fig. 745) arises from the arteria dorsalis pedis opposite the medial cuneiform bone; it passes laterally over the bases of the metatarsal bones deep to the tendons of the Extensores digitorum longus et brevis, and anastomoses with the lateral tarsal and lateral plantar arteries. It gives off the **second, third and fourth dorsal metatarsal arteries**, which run distally upon the corresponding Dorsal interosseous muscles; in the clefts between the toes each divides into two dorsal digital branches for the sides of the adjoining toes. At the proximal parts of the interosseous spaces the dorsal metatarsal arteries receive the proximal perforating branches from the plantar arch, and at the distal parts of the spaces they are joined by the distal perforating branches from the

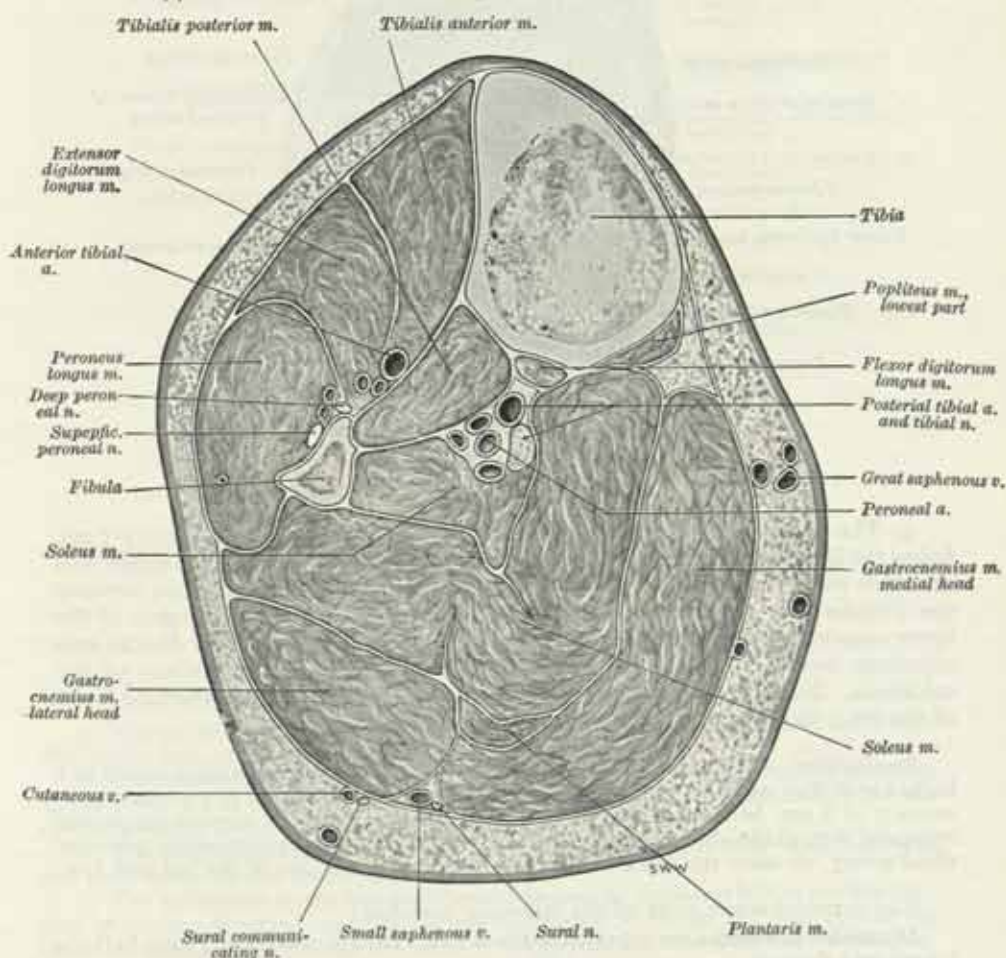
it passes into the sole; it runs distally on the first Dorsal interosseous muscle, and at the cleft between the first and second toes divides into two branches, one of which passes beneath the tendon of the Extensor hallucis longus, and is distributed to the medial border of the great toe; the other bifurcates to supply the adjoining sides of the great and second toes.

THE POSTERIOR TIBIAL ARTERY (figs. 743, 746)

The **posterior tibial artery** begins at the lower border of the Popliteus, opposite the interval between the tibia and fibula, and passes downwards and medially on the back of the leg. In the lower part of its course it is situated midway between the medial malleolus and the medial process of the tuber calcanei (medial tubercle of the calcaneus). It divides under cover of the origin of the Abductor hallucis into the *medial and lateral plantar arteries*.

Relations.—The posterior tibial artery lies successively upon the Tibialis posterior, the Flexor digitorum longus, the tibia and the back of the ankle-joint. Its upper part is covered by the Gastrocnemius and Soleus, and the deep transverse

FIG. 746.—A transverse section through the leg, four inches below the knee-joint.



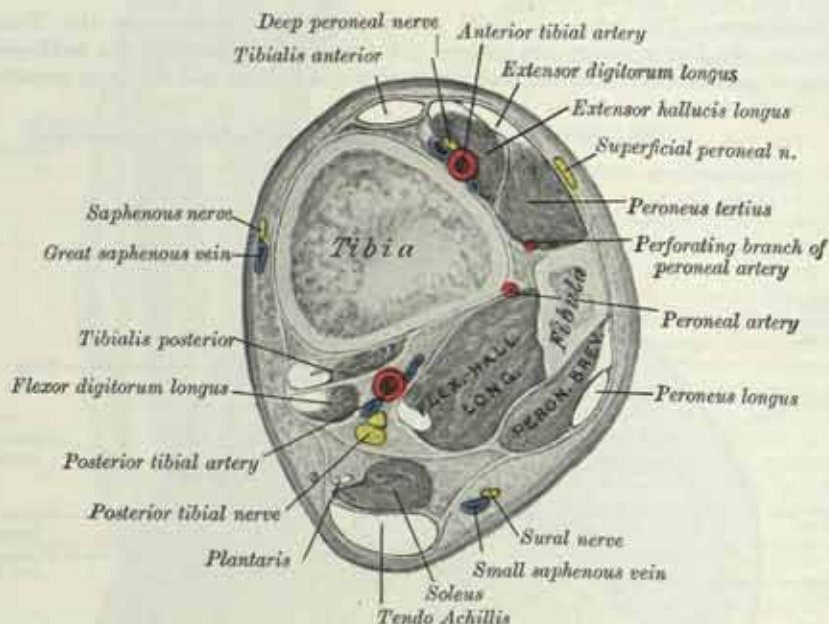
fascia of the leg; its lower part is covered only by the skin and fascia, and runs parallel with, and about 2.5 cm. in front of, the medial border of the tendo Achillis; its terminal part is deep to the flexor retinaculum and the Abductor hallucis muscle. It is accompanied by two veins, and by the tibial nerve, which lies at first on its medial side, but soon crosses it posteriorly, and is, in the greater part of its course, on its lateral side.

The relations and arrangement of the structures which pass from the back of the leg to the sole of the foot under cover of the flexor retinaculum are described on p. 684.

Surface Anatomy.—The posterior tibial artery runs from the middle line of the calf at the level of the neck of the fibula to a point midway between the medial malleolus and the prominence of the heel. In the latter situation its pulsations can be felt.

Branches.—1. The **circumflex fibular artery**, sometimes a branch of the anterior tibial artery, passes laterally, round the neck of the fibula, through the Soleus, and anastomoses with the lateral inferior genicular artery.

FIG. 747.—A transverse section through the leg, 6 cm. above the tip of the medial malleolus.



2. The **peroneal artery** (fig. 743) arises from the posterior tibial, about 2.5 cm. below the lower border of the Popliteus. It passes obliquely towards the fibula, and descends along the medial crest of that bone, contained in a fibrous canal between the Tibialis posterior and the Flexor hallucis longus, or in the substance of the latter muscle. It then runs behind the tibiofibular syndesmosis, and divides into calcanean branches, which ramify on the lateral and posterior surfaces of the calcaneus. Its *upper* part is covered by the Soleus and the deep transverse fascia of the leg; its *lower* part, by the Flexor hallucis longus.

Peculiarities.—The peroneal artery may spring from the posterior tibial artery at a higher level than usual, or may even be a branch of the popliteal artery; sometimes it arises 7 or 8 cm. below the inferior border of the Popliteus. It is more frequently increased than diminished in size; and then it either joins and reinforces the posterior tibial artery, or takes the place of that artery in the lower part of the leg and foot.

The peroneal artery gives off the following branches:

Muscular branches are supplied to the Soleus, Tibialis posterior, Flexor hallucis longus and Peronei.

A **nutrient artery** supplies the fibula, and is directed downwards.

A **perforating branch** pierces the interosseous membrane of the leg, about 5 cm. above the lateral malleolus, and reaches the front of the leg, where it anastomoses with the anterior lateral malleolar artery; it then descends in front of the tibiofibular syndesmosis, gives branches to the tarsus, and anastomoses with the lateral tarsal artery. The perforating branch is sometimes enlarged, and may take the place of the dorsalis pedis artery.

A **communicating branch** arises from the peroneal artery about 5 cm. above the lower end of the tibia, and joins the communicating branch of the posterior tibial artery.

The **calcanean** or terminal branches of the peroneal artery pass to the lateral side of the heel, and communicate with the anterior lateral malleolar artery and, on the back of the heel, with the calcanean branches of the posterior tibial artery.

3. The **nutrient artery** of the tibia arises from the posterior tibial artery near its origin, and, after supplying a few minute muscular branches, runs downwards to enter the nutrient canal in the bone, at a point immediately below the soleal line.

FIG. 748.—The arteries of the sole of the right foot.



4. **Muscular branches** of the posterior tibial artery are distributed to the Soleus and to the deep muscles on the back of the leg.

5. The **communicating branch** runs transversely across the back of the tibia about 5 cm. above its lower end, deep to the Flexor hallucis longus, and joins the communicating branch of the peroneal artery.

6. The **malleolar branch** is a small vessel which winds round the tibial malleolus and ends in the medial malleolar network.

7. The **calcanean branches** arise from the posterior tibial just before its division; they pierce the flexor retinaculum and are distributed to the fat and skin behind the tendo calcaneus and about the heel, and to the muscles on the tibial side of the sole, anastomosing with the peroneal and medial malleolar arteries, and, on the back of the heel, with the calcanean branches of the peroneal artery.

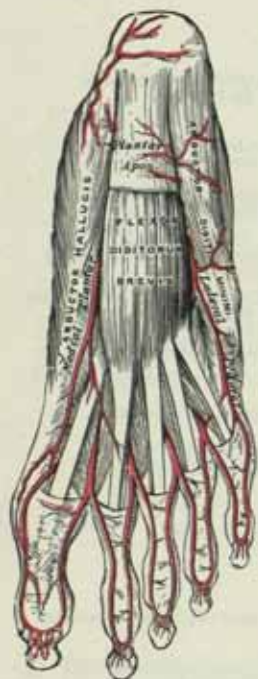
8. The **medial plantar artery** (figs. 748, 749), the smaller terminal branch of the posterior tibial artery, passes distally along the medial side of the foot in company with the medial plantar nerve, which lies to its lateral side. It is at first deep to the Abductor hallucis, and then runs distally between it and the Flexor digitorum brevis, both of which it supplies. At the base of the first metatarsal bone,

where it is much diminished in size, it passes along the medial border of the first toe and anastomoses with the first plantar metatarsal artery. It supplies three small superficial digital branches which accompany the digital branches of the medial plantar nerve and join the first, second and third plantar metatarsal arteries.

Surface Marking.—The trunk of the medial plantar artery begins midway between the medial malleolus and the prominence of the heel and runs forwards in the direction of the first interdigital cleft as far as the navicular bone.

9. The **lateral plantar artery** (fig. 748), the larger of the terminal branches of the posterior tibial artery, passes at first obliquely laterally and distally to the base

FIG. 749.—The plantar arteries. Superficial dissection.



of the fifth metatarsal bone in company with the lateral plantar nerve, which lies on its medial side. It then turns medially with the deep branch of the nerve, to the interval between the bases of the first and second metatarsal bones, where it unites with the *dorsalis pedis* artery, thus completing the *plantar arch*. As this artery passes laterally, it is first placed between the calcaneus and Abductor hallucis, and then between the Flexor digitorum brevis and Flexor accessorius; as it runs distally to the base of the fifth metatarsal bone it lies between the Flexor digitorum brevis and Abductor digiti minimi, and is covered by the plantar aponeurosis, superficial fascia and skin.

Branches.—The lateral plantar artery gives off muscular, superficial and anastomotic branches. The *muscular branches* supply the adjoining muscles; the *superficial branches* emerge along the line of the lateral intermuscular septum and supply the skin and subcutaneous tissue of the lateral part of the sole; the *anastomotic branches* run to the lateral border of the foot, where they anastomose with branches of the lateral tarsal and arcuate arteries. In addition, the lateral plantar artery sometimes gives off a *calcanean branch*, which pierces the origin of the abductor hallucis to supply the skin of the heel.

The **plantar arch** is deeply situated and extends from the base of the fifth metatarsal bone to the proximal part of the first interosseous space. It is convex distally, lies plantar to the bases of the second, third and fourth metatarsal bones and the corresponding Interossei, and dorsal to the oblique part of the Adductor hallucis.

Branches.—The plantar arch gives off three perforating and four plantar metatarsal branches, and distributes numerous twigs to the skin, fasciæ and muscles in the sole.

The three **perforating branches** ascend through the proximal parts of the second, third and fourth interosseous spaces, between the heads of the Dorsal interosseous muscles, and anastomose with the dorsal metatarsal arteries.

The four **plantar metatarsal arteries** (fig. 748) run distally between the metatarsal bones and in contact with the Interossei. Each divides into a pair of plantar digital arteries, which supply the adjacent sides of the toes. Near their points of division each plantar metatarsal artery sends dorsally a *distal perforating branch* to join the corresponding dorsal metatarsal artery. The first plantar metatarsal artery springs from the junction between the lateral plantar and the *dorsalis pedis* arteries (p. 830), and sends a digital branch to the medial side of the first toe. The digital branch for the lateral side of the fifth toe arises from the lateral plantar artery near the base of the fifth metatarsal bone.

Surface Marking.—Beginning at the termination of the posterior tibial, the lateral plantar artery crosses the sole obliquely to a point 2.5 cm. medial to the tuberosity of the fifth metatarsal bone. From here, a line drawn with a slight forward convexity to the proximal end of the first intermetatarsal space indicates the course of the plantar arch.

Applied Anatomy.—Wounds of the plantar arch are always serious, on account of

the depth of the vessel and the important structures which must be interfered with in an attempt to ligature it. They must be treated on similar lines to those of wounds of the palmar arches (p. 791).

THE VEINS

The veins convey the blood from the different parts of the body to the heart. They receive the blood from the capillaries, and unite with one another to form larger vessels which, in their passage towards the heart, increase in size as they receive tributaries, or join other veins. The veins are larger and more numerous than the arteries; hence, the capacity of the veins is greater than that of the arteries; the capacity of the pulmonary veins, however, exceeds that of the pulmonary arteries only to a slight extent. The veins are cylindrical like the arteries; their walls, however, are thin and they collapse when the vessels are empty, and the uniformity of their surfaces may show at intervals slight constrictions, caused by the presence of valves in their interior (p. 699). They communicate very freely with one another, especially in certain regions of the body. Thus, between the venous sinuses of the cranium, and between the veins of the neck, where obstruction would be attended by marked disturbance of the cerebral circulation, numerous anastomoses are found. Free communications also exist between the veins of the vertebral canal, and between the veins composing the various venous plexuses in the abdomen and pelvis.

The veins consist of two sets, viz. *pulmonary* and *systemic*.

The **pulmonary veins**, unlike other veins, contain oxygenated blood, which they return from the lungs to the left atrium of the heart.

The **systemic venous channels** return the venous blood from the body generally to the right atrium of the heart, and comprise three sets, viz. superficial and deep veins, and venous sinuses.

The **superficial veins** lie in the superficial fascia, immediately under the skin; they return the blood from these structures, and eventually join the deep veins. In their mode of origin and termination the superficial veins are subject to considerable variation.

The **deep veins** accompany the arteries, and are usually enclosed in the same sheaths with those vessels, an arrangement which helps venous return (p. 699). With the smaller arteries—as the radial, ulnar, brachial, tibial, peroneal—they exist generally in pairs, one lying on each side of the artery, and are called *venæ comitantes*. The larger arteries—such as the axillary, subclavian, popliteal and femoral—have usually only one accompanying vein. In certain regions, however, the deep veins do not accompany the arteries; for instance, the cerebral veins, the veins of the skull and vertebral canal, the hepatic veins in the liver, and the larger veins returning blood from the bones.

Venous sinuses are found only in the interior of the skull, and are canals between the two layers of the dura mater. *Their walls are devoid of muscular tissue.*

The **portal vein**, an appendage to the systemic venous system, is confined to the abdominal cavity, and conveys the venous blood from the spleen and the viscera of digestion to the liver, where it breaks up into a network of capillary-like vessels (sinusoids), from which the blood is drained by the hepatic veins to the inferior vena cava.

THE PULMONARY VEINS

The **pulmonary veins** return the oxygenated blood from the lungs to the left atrium of the heart. They are four in number, two from each lung, and are destitute of valves. They commence in the capillary network on the walls of the *alveoli* of the lungs, and, joining together, form one vessel from each lobule of the lung. These vessels, uniting successively, form a single trunk from each lobe, three from the right lung and two from the left. The vein from the middle lobe of the right lung generally unites with that from the upper lobe, so that ultimately two veins, a superior and an inferior, leave each lung; they perforate the fibrous layer of the pericardium and open separately into the upper and posterior part of the left atrium (fig. 655). Occasionally the three veins on the right side remain separate. Sometimes the two left pulmonary veins unite to form a single trunk before entering the heart.

In the root of the lung, the superior pulmonary vein lies in front of and a little below the pulmonary artery; the inferior is situated at the lowest part of the hilus of the lung and on a plane posterior to that of the superior vein. The principal bronchus is behind the pulmonary artery.

On the right side the upper pulmonary vein passes behind the superior vena cava, and the lower behind the right atrium.

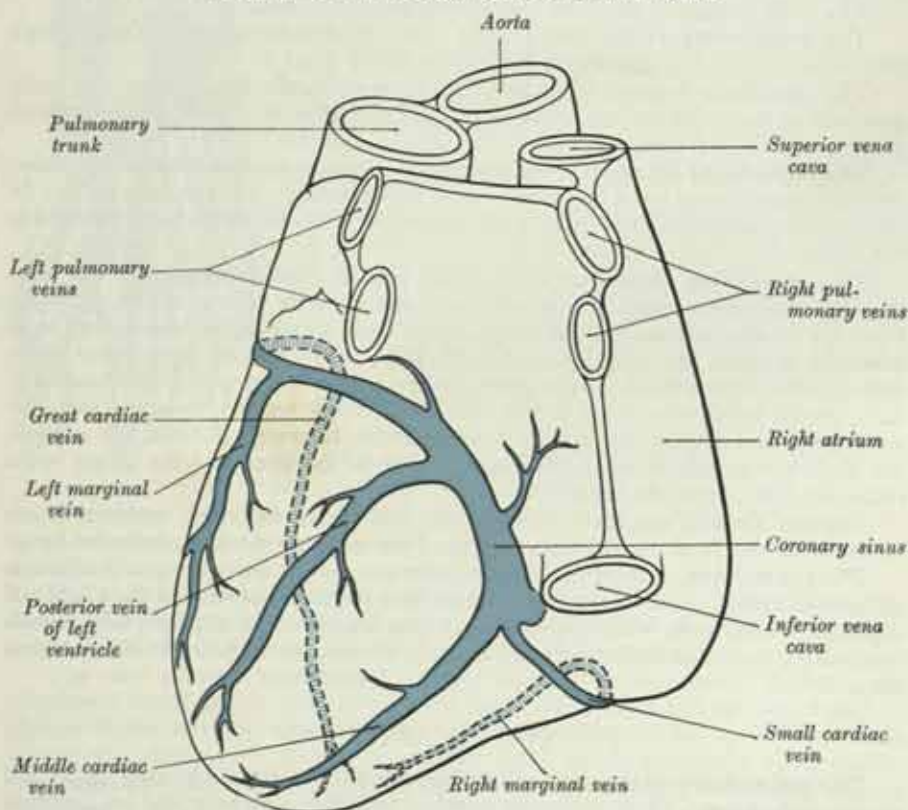
On the left side both pulmonary veins pass in front of the descending thoracic aorta.

Within the pericardium, their anterior surfaces are invested by the serous layer of this membrane. Between the veins of the right and left sides is found the oblique sinus of the pericardium.

THE SYSTEMIC VEINS

The **systemic veins** may be arranged into three groups: 1. The veins of the heart. 2. The veins of the upper limbs, head, neck and thorax, all of which end in the superior vena cava. 3. The veins of the lower limbs, abdomen and pelvis, all of which end in the inferior vena cava.

FIG. 750.—A scheme showing the veins of the heart.



THE VEINS OF THE HEART (fig. 750)

The coronary sinus.—Most of the veins of the heart open into the coronary sinus. This is a wide venous channel about 2 or 3 cm. long situated in the posterior part of the coronary sulcus (atrioventricular groove) of the heart (fig. 750), between the left atrium and left ventricle. It is completely surrounded by cardiac muscle, and some fibres from the left atrium may be carried over its posterior aspect. It ends in the right atrium between the opening of the inferior vena cava and the right

atrioventricular orifice, its aperture being guarded by a semilunar valve, named the *valve of the coronary sinus* (fig. 66o).

Its tributaries are the great, small, and middle cardiac veins, the posterior vein of the left ventricle, and the oblique vein of the left atrium, all of which, except the last, are provided with valves at their orifices.

1. The **great cardiac vein** (fig. 75o) begins at the apex of the heart and ascends in the anterior interventricular sulcus to reach the coronary sulcus. It then curves to the left in this groove, and, reaching the back of the heart, opens into the left extremity of the coronary sinus. It receives tributaries from the left atrium and from both ventricles, including the *left marginal vein*, which ascends along the left margin of the heart and is of considerable size.

2. The **small cardiac vein** (fig. 75o) runs in the coronary sulcus between the right atrium and ventricle posteriorly, and opens into the right extremity of the coronary sinus. It receives blood from the back of the right atrium and ventricle; the *right marginal vein* passes to the right along the lower margin of the heart and joins the small cardiac vein in the coronary sulcus, or opens directly into the right atrium.

3. The **middle cardiac vein** (fig. 75o) begins at the apex of the heart, runs backwards in the posterior interventricular groove, and ends in the coronary sinus near its right extremity.

4. The **posterior vein of the left ventricle** (fig. 75o) runs on the diaphragmatic surface of the left ventricle a little to the left of the middle cardiac vein; it usually opens into the coronary sinus, but may end in the great cardiac vein.

5. The **oblique vein of the left atrium** (fig. 75o) is a small vessel which descends obliquely on the back of the left atrium and ends in the coronary sinus near its left extremity; it is continuous above with the *ligament of the left vena cava* (p. 704), and the two structures are remnants of the left duct of Cuvier (p. 175).

The following cardiac veins do not end in the coronary sinus: (1) the **anterior cardiac veins**, comprising three or four small vessels which collect blood from the front of the right ventricle and open into the right atrium; the right marginal vein frequently opens into the right atrium, and is therefore sometimes regarded as belonging to this group; (2) the *venæ cordis minimæ*, comprising a number of minute veins, which lie in the muscular wall of the heart and open directly into its cavities, most of them into the atria, but a few into the ventricles.

THE VEINS OF THE HEAD AND NECK

The venous channels of the head and neck may be subdivided into: 1. The veins of the exterior of the head and face. 2. The veins of the neck. 3. The diploic veins, the meningeal veins, the veins of the brain and the venous sinuses of the dura mater.

THE VEINS OF THE EXTERIOR OF THE HEAD AND FACE (fig. 751)

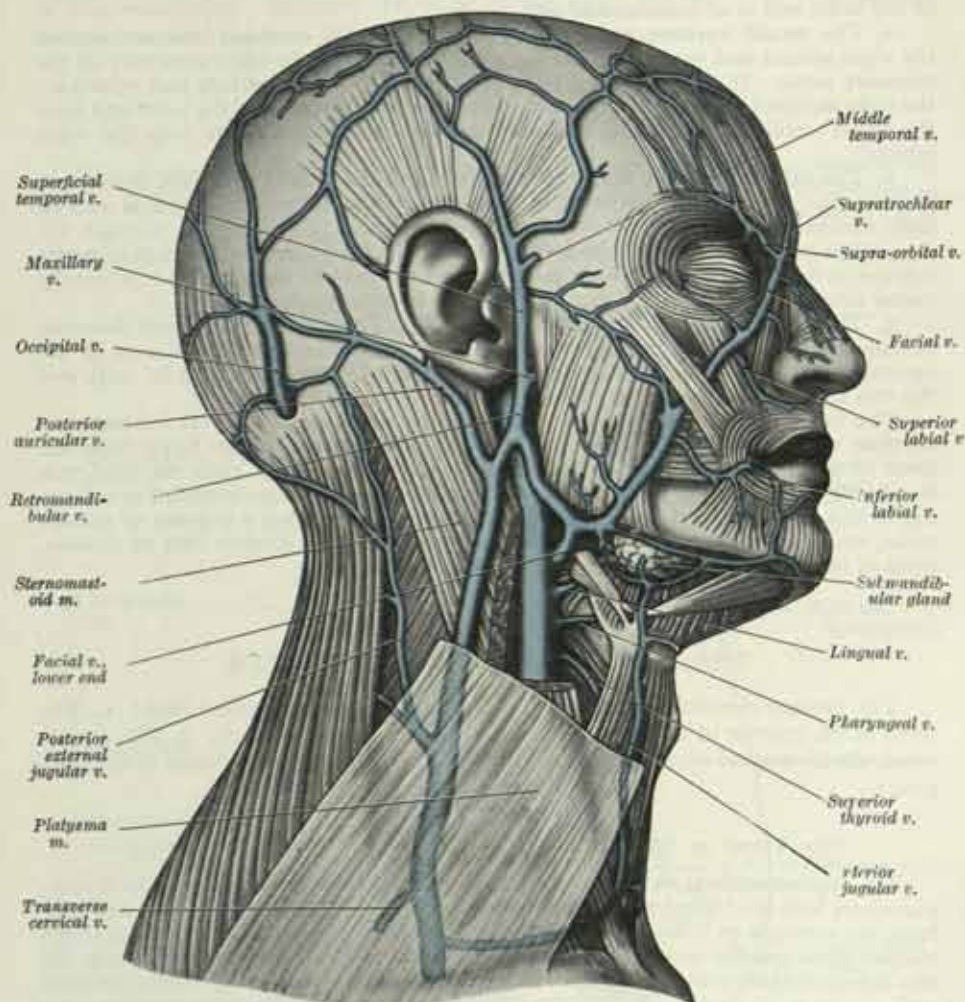
The **supratrochlear vein** begins on the forehead in a venous network which communicates with the frontal tributaries of the superficial temporal vein. Veins converge from the network to form a single trunk, which descends on the forehead near the median plane parallel with the vein of the opposite side. At the root of the nose the two supratrochlear veins are joined by a transverse branch which is called the *nasal arch*, and receives small veins from the dorsum of the nose. The supratrochlear veins then diverge, and at the medial angle of the orbit, each joins with the *supra-orbital vein* to form the *anterior facial vein*. Occasionally the supratrochlear veins unite in a single trunk, which divides at the root of the nose into the two anterior facial veins.

The **supra-orbital vein** begins near the zygomatic process of the frontal bone, where it communicates with the superficial and middle temporal veins. It courses medially along the upper margin of the orbital opening under cover of the *Orbicularis oculi*, and, at the medial angle of the eye, pierces this muscle and unites with the supratrochlear vein to form the *anterior facial vein*. It sends a branch through the supra-orbital notch into the orbital cavity to join the superior ophthalmic vein; as this branch traverses the supra-orbital notch it is joined by the frontal diploic vein.

The **facial vein**, formed by the junction of the supratrochlear and supra-orbital veins, runs obliquely downwards on the side of the root of the nose, to the level of the lower margin of the orbital opening. It then runs downwards and backwards behind the facial artery, but follows a less tortuous course. It passes under cover of the *Zygomaticus major*, *Risorius* and *Platysma*, descends along the

anterior border and then on the surface of the Masseter, crosses over the body of the mandible, and runs obliquely backwards, deep to the Platysma and superficial to the submandibular gland, Digastric and Stylohyoid. A little below and in front of the angle of the mandible, it is joined from above and behind by the anterior division of the retromandibular vein and then, descending across the loop of the lingual artery, the hypoglossal nerve and the external and internal carotid arteries, it enters the internal jugular vein near the greater cornu of the hyoid bone. From near the

FIG. 751.—The veins of the right side of the head and neck.



Note.—A part of the right sternomastoid muscle has been excised to expose the trunk of the internal jugular vein. The upper part of the right platysma muscle has been removed to show the external jugular vein, which is seen through the muscle in the lower part of the neck.

termination of the facial vein a branch of considerable size often runs down the anterior border of the Sternomastoid to join the lower part of the anterior jugular vein.

Tributaries.—At its commencement the facial vein is connected with the superior ophthalmic vein both directly and through the supra-orbital vein (see p. 837). In this way the facial vein is connected with the cavernous sinus into which the superior ophthalmic vein drains. It receives the veins of the ala nasi and, at a lower level, it receives a large branch, named the *deep facial vein*, from the pterygoid venous plexus. It is also joined by the inferior palpebral, the superior and inferior labial, the buccinator, the parotid and the masseteric veins. Below the mandible it receives the submental, tonsillar, external palatine and submandibular

veins. The facial vein may be joined by the vena comitans of the hypoglossal nerve, and often receives the pharyngeal and superior thyroid veins.

Applied Anatomy.—The facial vein is not so flaccid as most superficial veins, and, in consequence of this, shows less tendency to collapse when divided. It has, moreover, no valves. It communicates freely with the intracranial circulation, not only at its commencement and by the supra-orbital veins, which are connected with the ophthalmic vein, a tributary of the cavernous sinus, but also by the deep facial vein, which communicates through the pterygoid plexus, with the cavernous sinus (p. 854). These facts have an important bearing upon the surgery of some diseases; any phlegmonous inflammation of the face is liable to set up thrombosis in the facial vein which may extend upwards into the cranial sinuses; this has been known to follow in the case of ordinary carbuncle of the face. The position of the vein must be borne in mind when incisions are made for the relief of suppuration about the mandible.

The **superficial temporal vein** (fig. 751) begins on the side and vertex of the skull in a network which communicates with the corresponding vein of the opposite side, and with the supratrochlear, supra-orbital, posterior auricular and occipital veins. From this network, anterior and posterior tributaries arise, and unite above the zygomatic arch to form the superficial temporal vein, which is joined in this situation by the *middle temporal vein*. It then crosses the posterior root of the zygomatic arch, enters the substance of the parotid gland, and unites with the maxillary vein to form the *retromandibular (posterior facial) vein*.

Tributaries.—The superficial temporal vein receives some veins from the parotid gland, articular veins from the temporomandibular joint, anterior auricular veins from the auricle, and the *transverse facial* from the side of the face. The middle temporal vein, after receiving the *orbital vein*, which is formed by some lateral palpebral branches, passes backwards between the layers of the temporal fascia and then becomes superficial to join the superficial temporal vein.

The **pterygoid plexus** is of considerable size, and is situated partly between the Temporal and Lateral pterygoid muscles, and partly between the two Pterygoids. It receives the sphenopalatine, deep temporal, pterygoid, masseteric, buccal, dental, and greater palatine veins, the middle meningeal veins, and a branch or branches from the inferior ophthalmic vein. The pterygoid plexus anastomoses with the facial vein, through the *deep facial vein*; it is also connected with the cavernous sinus by veins which pass through the emissary sphenoidal foramen, foramen ovale and foramen lacerum.

The **maxillary vein** is a short trunk which accompanies the first part of the corresponding artery and is formed by a confluence of the veins of the pterygoid plexus. It passes backwards between the sphenomandibular ligament and the neck of the mandible, and unites with the superficial temporal vein to form the *retromandibular (posterior facial) vein*.

The **retromandibular vein**, so formed, descends in the substance of the parotid gland, superficial to the external carotid artery but deep to the facial nerve. It divides into two branches, an anterior which passes forwards and unites with the facial vein, and a posterior which is joined by the posterior auricular vein to form the external jugular vein. Occasionally the retromandibular vein gives no contribution to the external jugular, in which case the latter is small and the anterior jugular vein is then often very large.

The **posterior auricular vein** (fig. 751) begins on the posterior part of the side of the head, in a network which communicates with the tributaries of the occipital and superficial temporal veins. It descends behind the auricle, and joins the posterior division of the retromandibular vein in or just below the parotid gland to form the external jugular vein. It receives the stylomastoid vein and some tributaries from the cranial surface of the auricle.

The **occipital vein** (fig. 751) begins in a venous network at the posterior part of the skull. It pierces the cranial attachment of the Trapezius, dips into the suboccipital triangle and joins the deep cervical and vertebral veins. Occasionally it follows the course of the occipital artery and ends in the internal jugular vein; sometimes it joins the posterior auricular vein and, through it, opens into the external jugular vein. The parietal emissary vein connects it with the superior sagittal sinus, and the mastoid emissary vein with the transverse sinus. The occipital diploic vein sometimes joins it.

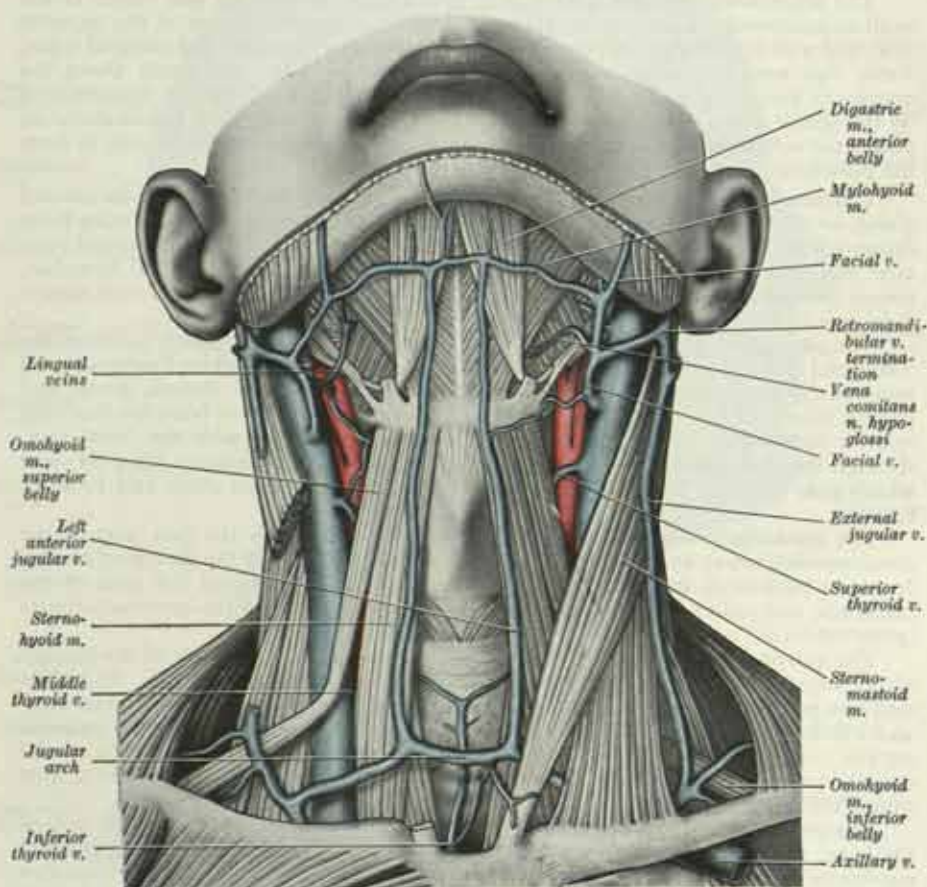
THE VEINS OF THE NECK (figs. 751, 752, 765)

The veins of the neck may be divided into those which lie superficial to the deep fascia and those which lie deep to it.

Superficial veins.—The **external jugular vein** (fig. 751) receives the greater part of the blood from the exterior of the cranium and from the deep parts of the

face, and is formed by the union of the posterior division of the retromandibular vein with the posterior auricular vein. It begins on a level with the angle of the mandible, just below the parotid gland, or, sometimes, in its substance, and runs down the neck, where its course is represented by a line drawn from the angle of the mandible to the middle of the clavicle. It crosses the Sternomastoid obliquely, and in the subclavian triangle perforates the deep fascia to end in the subclavian vein, lateral to, or in front of, the Scalenus anterior; the wall of the vein is adherent to the circumference of the opening in the deep fascia. It is covered by the Platysma, superficial fascia, and skin, and separated from the Sternomastoid by the investing layer of the deep cervical fascia; it crosses the transverse cervical nerve, and its upper half runs

FIG. 752.—The veins of the front of the neck.



parallel with the great auricular nerve, which ascends behind it. The external jugular vein varies in size, bearing an inverse proportion to the other veins of the neck; it is occasionally double. It is provided with two pairs of valves, a lower pair at its entrance into the subclavian vein, an upper about 4 cm. above the clavicle. The portion of the vein between the two sets of valves is often dilated, and is sometimes termed the *sinus*. These valves do not prevent regurgitation of the blood.

Tributaries.—In addition to the veins which unite to form it, the external jugular vein receives the posterior external jugular, and, near its termination, the transverse cervical, suprascapular and anterior jugular veins; in the parotid gland it is frequently joined by a branch from the internal jugular vein. The occipital vein occasionally opens into it.

The **posterior external jugular vein** begins in the occipital region and returns the blood from the skin and superficial muscles in the upper and posterior part of the neck. It opens into the middle part of the external jugular vein.

The **anterior jugular vein** (figs. 751, 752) begins near the hyoid bone by the confluence of several superficial veins from the submandibular region. It descends between the anterior median line and the anterior border of the Sternomastoid; at the lower part of the neck it turns laterally under cover of that muscle, but superficial to the depressors of the hyoid bone, and opens into the termination of the external jugular vein, or into the subclavian vein. Its size varies considerably, and usually bears an inverse proportion to that of the external jugular vein. It communicates with the internal jugular vein and receives as tributaries some laryngeal veins, and occasionally a small thyroid vein. There are usually two anterior jugular veins, a right and a left; just above the sternum they are united by a large transverse trunk, termed the *jugular arch*, which receives tributaries from the inferior thyroid veins. The anterior jugular veins have no valves. They may be replaced by a single trunk which descends in the anterior median line of the neck.

Surface Anatomy of the Superficial Veins.—Usually the *external jugular vein* is easily seen crossing the sternomastoid muscle obliquely. When it is not obvious, it can be brought into view by the effort of blowing with the mouth closed. The *anterior jugular vein* can often be rendered visible in the upper two-thirds of the neck in a similar manner. The terminal part of the facial vein runs from a point on the lower border of the mandible at the anterior border of the masseter to join the internal jugular vein just below the greater cornu of the hyoid bone.

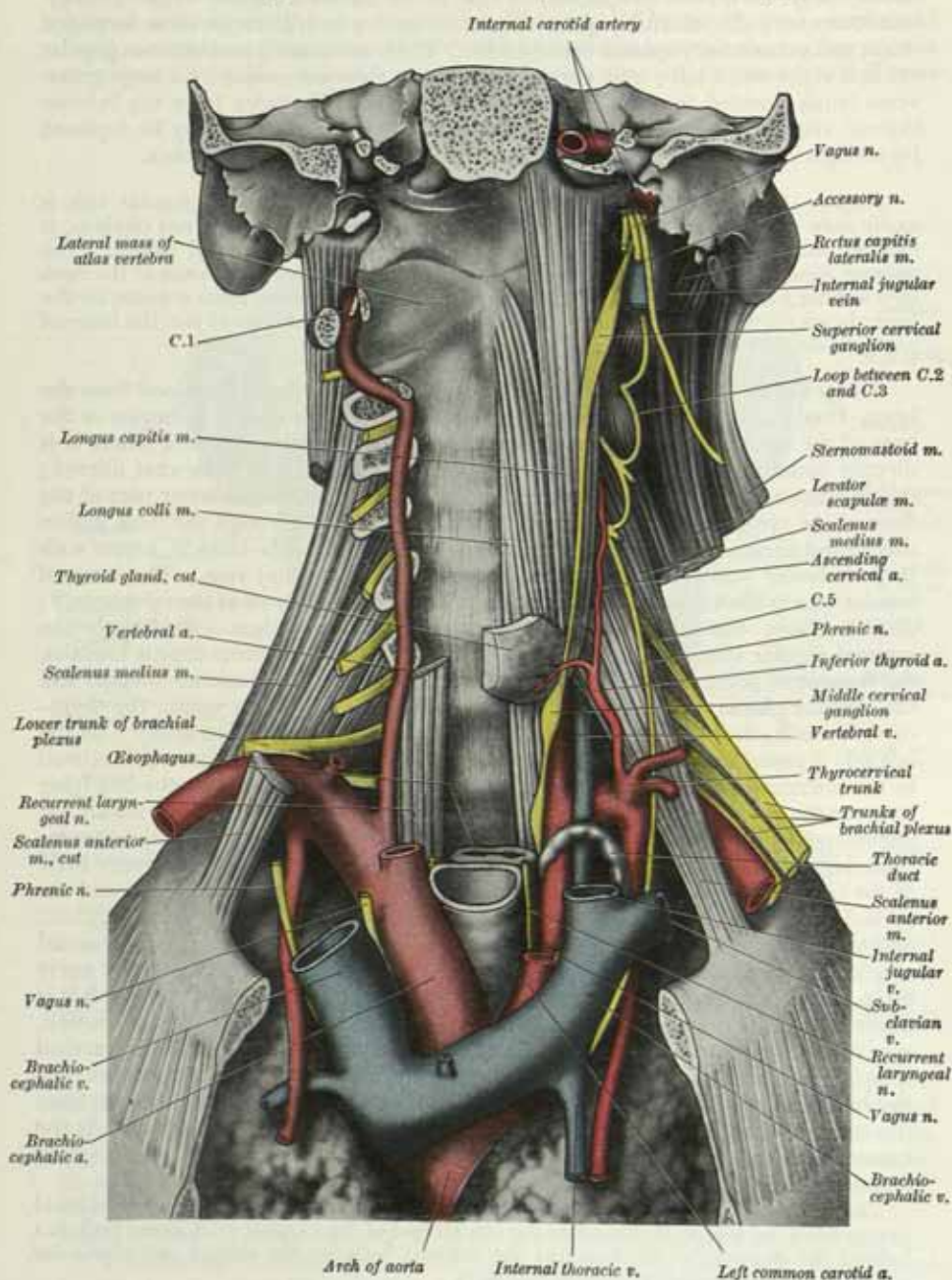
Deep Veins.—The **internal jugular vein** (fig. 752) collects the blood from the brain, from the superficial parts of the face, and from the neck. It begins at the base of the skull in the posterior compartment of the jugular foramen, where it is directly continuous with the sigmoid sinus. At its origin it is somewhat dilated; this dilatation, which is called the *superior bulb*, lies below the posterior part of the floor of the tympanic cavity. The vein runs downwards through the neck within the carotid sheath (fig. 566), and, behind the sternal end of the clavicle, unites with the subclavian vein to form the brachiocephalic (innominate) vein. The internal jugular vein is dilated near its termination to form what is known as the *inferior bulb*; directly above this bulb the vein contains a pair of valves. *Posteriorly* the internal jugular vein rests, from above downwards, on the Rectus capitis lateralis, the transverse process of the atlas, the Levator scapulae, the Scalenus medius and the cervical plexus; then on the Scalenus anterior, the phrenic nerve, the thyrocervical trunk, the vertebral vein and the first part of the subclavian artery; on the left side it passes in front of the thoracic duct (fig. 753). *Medially* the vein is related to the internal and common carotid arteries, and to the vagus nerve, the last lying between the vein and the arteries but on a plane posterior to them. *Superficially* the vein is overlapped by the upper part, and covered by the lower part, of the Sternomastoid, and is crossed by the posterior belly of the Digastric and the superior belly of the Omohyoid. Above the Digastric, it is covered by the parotid gland and the styloid process, and is crossed by the accessory nerve and the posterior auricular and occipital arteries. Between the Digastric and the Omohyoid, the sternomastoid arteries and the inferior ramus of the ansa cervicalis cross the vein, but the nerve often passes between it and the common carotid artery. Below the Omohyoid, it is covered by the infrahyoid muscles, in addition to the Sternomastoid, and is crossed, superficial to the infrahyoid muscles, by the anterior jugular vein. The deep cervical lymph nodes lie along the course of the vein, mainly on its superficial aspect. At the root of the neck the right internal jugular vein is placed at a little distance from the common carotid artery, while the left vein usually overlaps the artery. At the base of the skull the internal carotid artery is in front of the internal jugular vein, and is separated from it by the last four cranial nerves.

Surface Anatomy.—The internal jugular vein can be represented by a broad band drawn from the lobule of the ear to the medial end of the clavicle; its lower bulb lies behind the depression which marks the interval between the sternal and clavicular heads of the sternomastoid muscle (fig. 687).

Tributaries.—The internal jugular vein receives the inferior petrosal sinus, the facial, lingual, pharyngeal, superior and middle thyroid veins, and sometimes the occipital vein. In the upper part of the neck it may communicate with the external jugular vein. The thoracic duct opens into the angle of union of the left subclavian and internal jugular veins, and the right lymphatic duct into the angle of union of the right subclavian and internal jugular veins.

The **inferior petrosal sinus** leaves the skull through the anterior part of the jugular foramen and, crossing either lateral or medial to the ninth, tenth and eleventh cranial nerves, joins the superior bulb of the internal jugular vein.

FIG. 753.—A drawing of a dissection of the prevertebral and upper thoracic regions showing the vessels, etc., near the root of the neck, the cervical course of the vertebral artery, and the structures which lie posterior to the internal jugular vein.

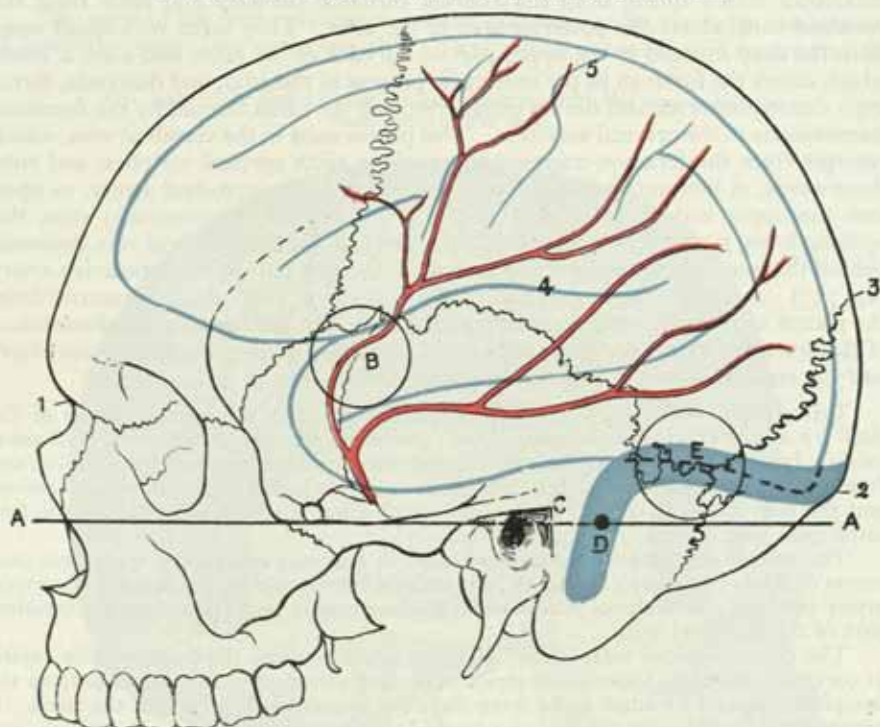


The **veins of the tongue** follow two different routes. (1) The *dorsales linguae* veins drain the dorsum and sides of the tongue and join the *lingual veins*, which accompany the lingual artery, lying in the interval between the Hyoglossus and the Genioglossus muscles. Near the greater cornu of the hyoid bone the lingual veins join the internal jugular vein. (2) The *profunda linguae* vein commences near the tip of the tongue and runs backwards close to the mucous membrane on the inferior

surface of the organ (fig. 1144). Near the anterior border of the Hyoglossus muscle it joins the *sublingual vein*, from the salivary gland of the same name, to form the *vena comitans n. hypoglossi*, which runs backwards in the interval between the Mylohyoid and the Hyoglossus muscles in company with the hypoglossal nerve to end by joining the facial, the internal jugular or the lingual vein.

The **pharyngeal veins** begin in the *pharyngeal plexus* on the outer surface of the pharynx, and, after receiving some meningeal veins and the vein corresponding to the artery of the pterygoid canal, end in the internal jugular vein. They occasionally open into the facial, the lingual, or the superior thyroid vein.

FIG. 754.—The relations of the brain, the middle meningeal artery and the transverse and sigmoid sinuses to the surface of the skull.



1. Nasion. 2. Inion. 3. Lambda. 4. Lateral cerebral sulcus. 5. Central sulcus. AA. Reid's base-line, which passes through the lower margin of the orbital opening and the upper margin of the external acoustic meatus. B. Point for trephining over the anterior branch of the middle meningeal artery. C. Supramental triangle. D. Sigmoid sinus. E. Point for trephining over the transverse sinus, exposing dura mater of both cerebrum and cerebellum. The outline of the cerebral hemisphere is indicated in blue; the course of middle meningeal artery in red.

The **superior thyroid vein** (fig. 765) begins in the substance and on the surface of the thyroid gland, by tributaries corresponding with the branches of the superior thyroid artery. It accompanies this artery, receives the superior laryngeal and cricothyroid veins, and ends in the internal jugular or in the facial vein.

The **middle thyroid vein** (fig. 765) collects the blood from the lower part of the thyroid gland, and receives some veins from the larynx and trachea. It crosses in front of the common carotid artery, and ends in the lower part of the internal jugular vein under cover of the superior belly of the Omohyoid.

The inferior thyroid veins are described on p. 858.

The **facial** and **occipital veins** have been described (pp. 837, 839).

Applied Anatomy.—The internal jugular vein may require ligature in cases of septic thrombosis of the sigmoid sinus, secondary to suppurative otitis media, in order to prevent septic emboli being carried into the general circulation. When the thrombosis involves the superior bulb of the internal jugular vein, the glossopharyngeal, vagus and accessory nerves may be paralysed. The hypoglossal nerve is sometimes paralysed by extension of the thrombus to the veins of the hypoglossal canal.

The internal jugular vein is also important surgically, because it is surrounded by a number of deep cervical lymph nodes; and when these are enlarged in tuberculous

or malignant disease, they are apt to adhere to the vessel, rendering their removal difficult and often dangerous.

Cardiac pulsation is often demonstrable in the internal jugular vein at the root of the neck. There are no valves in the brachiocephalic veins or superior vena cava; in consequence, the systole of the right atrium causes a wave to pass up these vessels, and when the conditions are favourable this wave appears as a somewhat feeble flicker over the internal jugular vein at the root of the neck, quite distinct from, and just preceding, the more forcible impulse transmitted from the underlying common carotid artery and due to the ventricular systole. This atrial systolic venous impulse is much increased in conditions in which the right atrium is abnormally distended with blood or is hypertrophied, as is often the case in disease of the mitral valve.

The **vertebral vein** is formed in the suboccipital triangle, from numerous small tributaries which spring from the internal vertebral plexuses and issue from the vertebral canal above the posterior arch of the atlas. They unite with small veins from the deep muscles at the upper part of the back of the neck, and form a vessel which enters the foramen in the transverse process of the atlas, and descends, forming a dense plexus around the vertebral artery, in the canal formed by the foramina transversaria of the cervical vertebrae. This plexus ends in the vertebral vein, which emerges from the foramen transversarium of the sixth cervical vertebra, and runs downwards, at first anterior and then anterolateral to the vertebral artery, to open into the upper and posterior part of the brachiocephalic (innominate) vein, the opening being guarded by a pair of valves. In its course the vertebral vein descends behind the internal jugular vein and in front of the first part of the subclavian artery (fig. 753). A small vein, termed the *accessory vertebral vein*, usually descends from the plexus around the vertebral artery, passes through the foramen transversarium of the seventh cervical vertebra, and curves forwards between the subclavian artery and the cervical pleura to join the brachiocephalic vein.

Tributaries.—The vertebral vein communicates with the sigmoid sinus of the skull by a vein which passes through the (posterior) condylar canal, when that canal exists. It receives branches from the occipital vein, from the prevertebral muscles, and from the internal and external vertebral plexuses. It is joined by the anterior vertebral and the deep cervical veins; close to its termination it sometimes receives the first intercostal vein.

The **anterior vertebral vein** commences in a plexus around the transverse processes of the upper cervical vertebrae, descends in company with the ascending cervical artery between the Scalenus anterior and Longus capitis, and opens into the terminal part of the vertebral vein.

The **deep cervical vein** accompanies its artery between the Semispinales capitis et cervicis. It begins in the suboccipital region by communicating branches from the occipital vein and by small veins from the deep muscles at the back of the neck. It receives tributaries from the plexuses around the spines of the cervical vertebrae, and passes forwards between the transverse process of the seventh cervical vertebra and the neck of the first rib to end in the lower part of the vertebral vein.

THE DIPLOIC VEINS (fig. 755)

The **diploic veins** occupy channels in the diploë of the cranial bones and are devoid of valves. They are large, and exhibit pouch-like dilatations at irregular intervals; their walls are thin, and formed of endothelium supported by a layer of elastic tissue. In radiographs of the skull the diploic veins may show as relatively transparent bands which may be 3 or 4 mm. wide (Pl. III). They are absent from the skull of the newly-born and are formed after the appearance of the diploë at the age of about two years.

They communicate with the meningeal veins, the sinuses of the dura mater, and the veins of the pericranium. They comprise (1) the *frontal diploic vein*, which emerges from the bone at the supra-orbital foramen and opens into the supra-orbital vein; (2) the *anterior temporal (parietal) diploic vein*, which is confined chiefly to the frontal bone and pierces the greater wing of the sphenoid bone to end in the sphenoparietal sinus or in the anterior deep temporal vein; (3) the *posterior temporal (parietal) diploic vein*, which is situated in the parietal bone; it descends to the mastoid angle of the parietal bone and joins the transverse sinus through an aperture placed at that angle or through the mastoid foramen; and (4) the *occipital diploic vein*, the largest of the four, which is confined to the occipital bone and opens into the occipital vein, or into the transverse sinus near the confluence of the sinuses.

In addition, numerous small diploic veins (fig. 921) pierce the inner table close to the margins of the superior sagittal sinus and terminate in the venous lacunæ (p. 847).

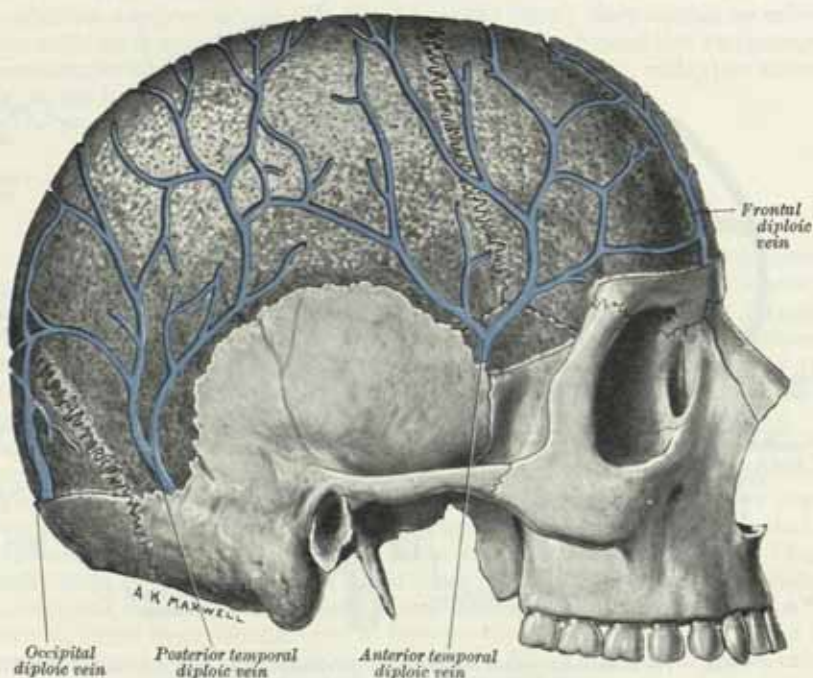
MENINGEAL VEINS

The meningeal veins begin from plexiform vessels in the dura mater and drain into efferent vessels which lie in the superficial layer of the dura. The efferents communicate with the lacunæ of the superior sagittal sinus, with other cranial sinuses, including those which accompany the middle meningeal arteries (p. 853) and with the diploic veins.

THE VEINS OF THE BRAIN

The veins of the brain possess no valves, and their walls, owing to the absence of muscular tissue, are extremely thin. They pierce the arachnoid mater and the

FIG. 755.—The veins of the diploë. Displayed by the removal of the outer table of the skull.



inner or meningeal layer of the dura mater, and open into the cranial venous sinuses. They comprise two sets, cerebral and cerebellar.

The **cerebral veins** are divisible into external and internal groups, according as they drain the outer surfaces or the inner parts of the hemispheres.

The **external cerebral veins** are the superior, middle and inferior.

The **superior cerebral veins**, eight to twelve in number on each hemisphere, drain the superolateral and medial surfaces of the hemispheres, and are mainly lodged in the sulci between the gyri, but some run across the gyri. They ascend to the superomedial border of the hemisphere, where they receive small veins from the medial surface of the hemisphere, and open into the superior sagittal sinus; the anterior veins run nearly at right angles to the sinus; the posterior and larger veins are directed obliquely forwards, and thus open into the sinus in a direction opposed to the current of the blood contained within it.

It has been suggested * that this arrangement prevents the collapse of the thin-walled cerebral veins which might otherwise result from a rise of intracranial pressure, but the causative factor would appear to be the backward growth of the cerebral hemispheres and the consequent displacement of the vessels during development.†

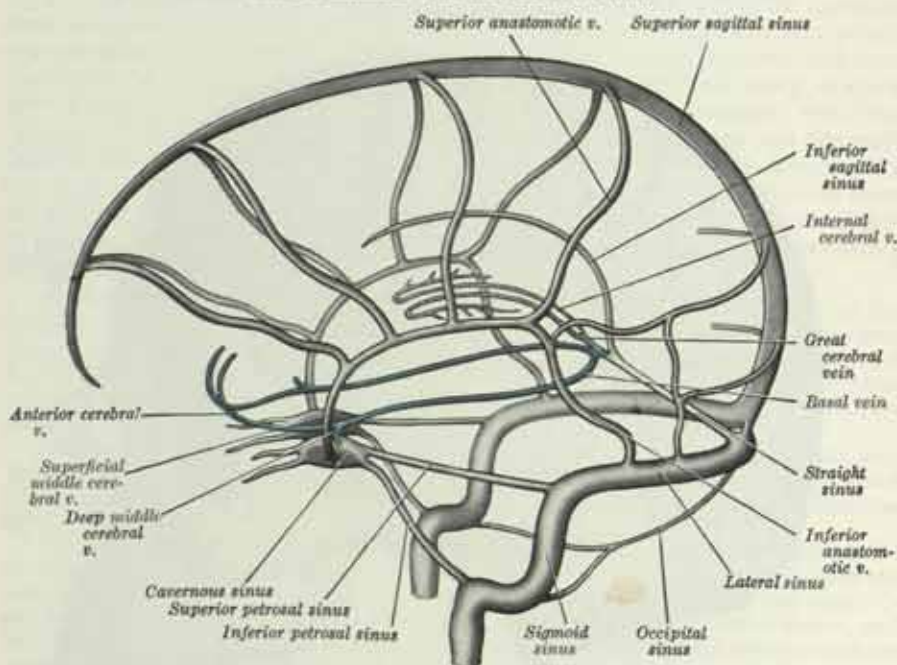
* J. S. B. Stopford, *Journal of Anatomy*, 64, 1930.

† J. E. A. O'Connell, *Brain*, 57, 1934.

The *superficial middle cerebral vein* begins on the lateral surface of the hemisphere, and, following the posterior ramus and the stem of the lateral sulcus, ends in the cavernous sinus. The *superior anastomotic vein* runs backwards and upwards between the middle cerebral vein and the superior sagittal sinus, and thus a communication is established between the superior sagittal and cavernous sinuses. A second vein, named the *inferior anastomotic vein*, courses over the temporal lobe, and connects the middle cerebral vein to the transverse sinus.

The *inferior cerebral veins* are of small size, and drain the under surface of the hemisphere. Those on the orbital surface of the frontal lobe join the superior cerebral veins, and through these open into the superior sagittal sinus; those of the temporal lobe anastomose with the basal and middle cerebral veins, and join the cavernous, superior petrosal and transverse sinuses.

FIG. 756.—A schéma to show the plan of the venous sinuses of the dura mater and their connexions with the cerebral veins.



Note.—The more deeply-placed cerebral veins are shown in blue, while the cerebral veins which lie inside the brain are shown in interrupted blue.

The *basal vein* begins at the anterior perforated substance by the union of (a) a small *anterior cerebral vein*, which accompanies the anterior cerebral artery, (b) the *deep middle cerebral vein*, which receives the tributaries from the insula and neighbouring gyri, and runs in the floor of the lateral cerebral sulcus, and (c) the *striate veins*, which pass through the anterior perforated substance. The basal vein passes backwards round the cerebral peduncle and ends in the great cerebral vein; (fig. 756) it receives tributaries from the interpeduncular fossa, the inferior horn of the lateral ventricle, the parahippocampal gyrus and the mid-brain.

The *internal cerebral veins*, two in number, drain the deep parts of the hemisphere; each is formed near the interventricular foramen by the union of the *thalamostriate* and *choroid veins*. They run backwards parallel with each other, between the layers of the tela chorioidea of the third ventricle, and below the splenium of the corpus callosum, where they unite to form the *great cerebral vein* (fig. 756).

The *thalamostriate vein* runs in the groove between the caudate nucleus and the thalamus, receives numerous veins from both of these structures, and unites behind the anterior column of the fornix with the choroid vein, to form the internal cerebral vein. The *choroid vein* runs along the whole length of the

choroid plexus, and receives veins from the hippocampus, the fornix, and the corpus callosum.

The **great cerebral vein**, formed by the union of the two internal cerebral veins, is a short median trunk which curves sharply upwards around the splenium of the corpus callosum and opens into the anterior extremity of the straight sinus, after receiving the right and left basal veins.

The **cerebellar veins** are placed on the surface of the cerebellum, and consist of two sets, superior and inferior. Some of the *superior cerebellar veins* pass forwards and medially, across the superior vermis, to end in the straight sinus and in the internal cerebral veins; others run laterally to the transverse and superior petrosal sinuses. The *inferior cerebellar veins*, of large size, end in the sigmoid, superior petrosal and occipital sinuses.

THE VENOUS SINUSES OF THE DURA MATER (figs. 756 to 761)

The sinuses of the dura mater are venous channels which drain the blood from the brain; they are situated between the two layers of the dura mater and are lined by endothelium continuous with that which lines the veins; they contain no valves, and their walls are devoid of muscular tissue. They may be divided into two groups: (1) a posterosuperior, at the upper and posterior parts of the skull, and (2) an antero-inferior, at the base of the skull.

1. The posterosuperior group of venous sinuses:

Superior sagittal.	Two transverse.
Inferior sagittal.	Two sigmoid.
Straight.	Occipital.

The **superior sagittal sinus** (figs. 756 to 758, 919) occupies the attached, convex margin of the falx cerebri. It commences in front of the crista galli, where it receives a vein from the nasal cavity on the rare occasions when the foramen cæcum is patent; it runs backwards, grooving the inner surface of the frontal bone, the adjacent margins of the two parietal bones, and the squamous part of the occipital bone; near the internal occipital protuberance it deviates to one or other side (usually the right), and is continued as the corresponding transverse sinus. It is triangular in cross-section, and gradually increases in size as it passes backwards. Its inner surface presents the openings of the superior cerebral veins, projecting arachnoid granulations, and numerous fibrous bands which cross the inferior angle of the sinus; the sinus also communicates through small openings with irregularly-shaped *venous lacunæ*, which are situated in the dura mater near the sinus. There are usually three lacunæ on each side of the sinus: a small frontal, a large parietal, and an occipital, which is intermediate in size between the other two (Sargent *). In elderly subjects these lacunæ tend to become continuous with one another as one elongated lacuna that is present on each side.† Many fine fibrous bands cross the lacunæ, and numerous arachnoid granulations project into them from below. The superior sagittal sinus receives the superior cerebral veins, and, near the posterior extremity of the sagittal suture, veins from the pericranium which pass through the parietal foramina; the venous lacunæ receive the diploic and meningeal veins.

According to Le Gros Clark ‡ the lacunæ should be described as a complicated meshwork of veins into which the diploic veins and the superior terminations of the meningeal veins open. The superior cerebral veins never open into the lacunæ, but pass beneath them and open directly into the superior sagittal sinus.

The *confluence of the sinuses* (fig. 759), is the term applied to the dilated posterior extremity of the superior sagittal sinus. It is lodged on one side (generally the right) of the internal occipital protuberance, and from it the transverse sinus of the same side is derived. It receives also the blood from the occipital sinus, and is connected by a channel with the commencement of the opposite transverse sinus.

Applied Anatomy.—The communications which take place between the superior sagittal sinus and the veins of the nose, scalp, and diploë, cause it to be at times the seat of infective thrombosis from suppurative processes in these parts.

* Percy Sargent, *J. Anat. and Physiol.*, 45, 1910.

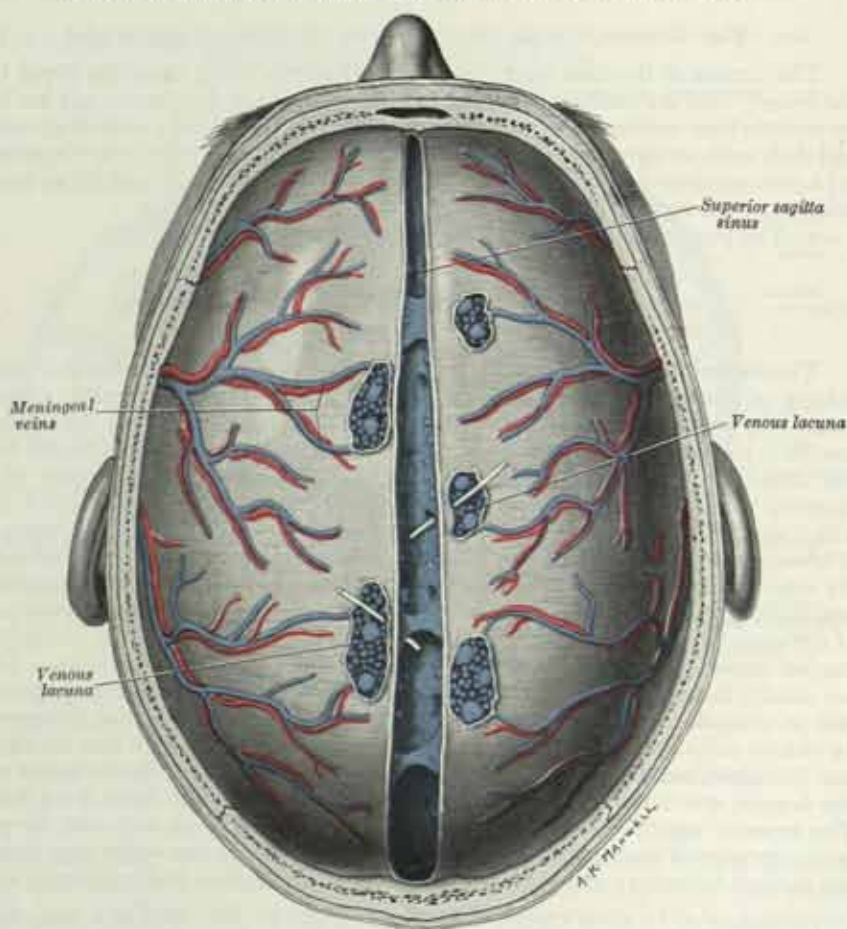
† J. E. A. O'Connell, *Brain*, 57, 1934.

‡ W. E. Le Gros Clark, *J. Anat.*, 55, 1920.

The **inferior sagittal sinus** (fig. 758) is contained in the posterior one-half or two-thirds of the free margin of the falx cerebri. It increases in size as it passes backwards, and ends in the straight sinus. It receives several veins from the falx cerebri, and occasionally a few from the medial surfaces of the hemispheres.

The **straight sinus** (figs. 758, 759) is situated in the line of junction of the falx cerebri with the tentorium cerebelli. It is triangular in cross-section and is traversed by a few transverse bands. It runs backwards and downwards from the end of the inferior sagittal sinus to the transverse sinus of the side opposite to that into which the superior sagittal sinus is prolonged. Its terminal part communicates by a cross

FIG. 757.—The superior sagittal sinus laid open after the removal of the skull-cap. Some of the fibrous bands which cross the sinus are clearly seen; from two of the lacunæ, bristles are passed into the sinus. (From a young subject.)



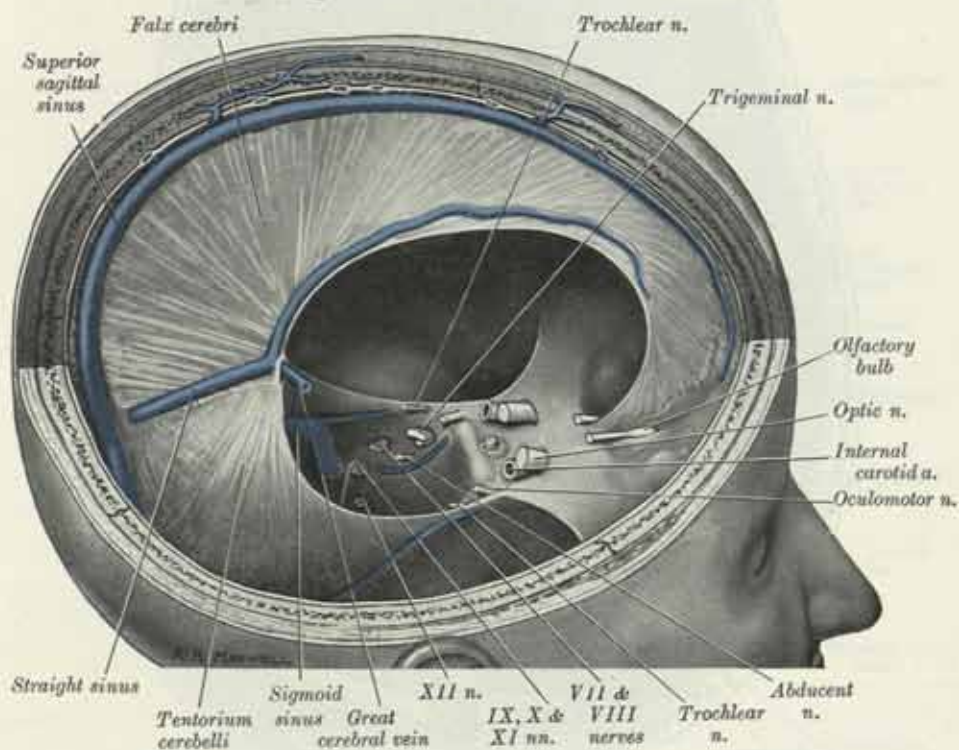
branch with the confluence of the sinuses. Besides the inferior sagittal sinus, it receives some of the superior cerebellar veins, and, at its commencement, the great cerebral vein, the site of the opening of this vein being marked by a dilatation. A small body, resembling an arachnoid granulation, projects into the anterior end of the floor of the sinus at its angle of union with the great cerebral vein.* This body, which contains a sinusoidal plexus of blood-vessels, is believed to become engorged from time to time and may then act as a ball valve mechanism to control the outflow from the great cerebral vein and so to influence the secretion of cerebrospinal fluid by the choroid plexuses of the lateral ventricles. Other masses of cavernous tissue have been described in relation with the dural sinuses.† Engorgement of these may influence the blood-flow through the sinuses.

* W. E. Le Gros Clark, *Brit. Med. Journ.*, March 23rd, 1940.

† J. Baló, *Anat. Rec.*, 106, 1950.

The **transverse sinuses** (fig. 759, 760) are of large size, and begin at the internal occipital protuberance; one, generally the right, being the direct continuation of the superior sagittal sinus, the other of the straight sinus. Each transverse sinus passes laterally and forwards to the posterior part of the petrous portion of the temporal bone, where it becomes continuous with the sigmoid sinus. It lies in the attached margin of the tentorium cerebelli, at first on the squama of the occipital bone and then on the mastoid angle of the parietal bone. It describes a gentle curve, convex upwards, and increases in size as it proceeds forwards. The transverse sinuses are triangular on transverse section, and are frequently of unequal size, that formed by the superior sagittal sinus being the larger. At the point where they become continuous with the sigmoid sinuses, they are joined by the superior petrosal sinuses; and in their course they receive some inferior cerebral, inferior cerebellar, and diploic veins, and the inferior anastomotic vein (p. 846). The *petrosquamous sinus*, when

FIG. 758.—The dura mater and its processes. Exposed by removing part of the right half of the skull, and the brain.



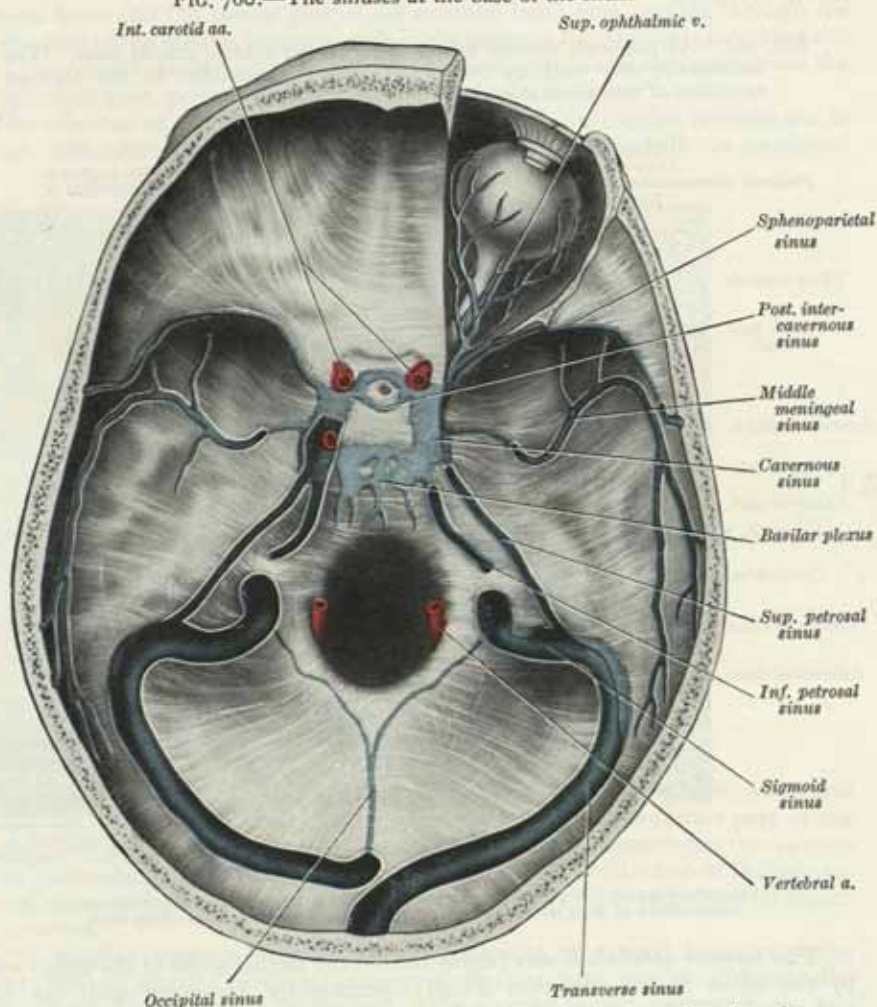
present, runs backwards along the junction of the squama and petrous portion of the temporal bone, and opens into the transverse sinus. Anteriorly, it communicates with the external jugular vein through a postglenoid (p. 322) or a squamosal (p. 321) foramen.

The **sigmoid sinuses** (fig. 760) are directly continuous with the transverse sinuses at the point where the latter leave the tentorium cerebelli. Each sigmoid sinus curves downwards and medially in a deep groove on the mastoid part of the temporal bone, crosses the jugular process of the occipital bone, and then turns forwards to become continuous with the superior bulb of the internal jugular vein in the posterior part of the jugular foramen. Anteriorly a very thin plate of bone separates the upper part of the sigmoid sinus from the tympanic antrum and mastoid air-cells. Each sinus communicates with the veins of the pericranium by means of the mastoid and condylar emissary veins.

The **occipital sinus** (fig. 760), the smallest of the cranial sinuses, is situated in the attached margin of the falx cerebelli, and is generally unpaired, but two may be present. It commences near the margin of the foramen magnum in several small venous channels, one of which joins the terminal part of the sigmoid sinus; it

The tributaries of the cavernous sinus are the superior ophthalmic vein, a branch from the inferior ophthalmic vein, the superficial middle cerebral vein, some inferior cerebral veins, and the sphenoparietal sinus; the central vein of the retina and the anterior trunk of the middle meningeal sinus sometimes open into it. The cavernous sinus communicates with the transverse sinus through the superior petrosal sinus; with the internal jugular vein through the inferior petrosal sinus and a plexus of veins on the internal carotid artery; with the pterygoid venous plexus by veins which pass through the emissary sphenoidal foramen, foramen ovale, and foramen lacerum; and with the facial vein through the superior ophthalmic

FIG. 760.—The sinuses at the base of the skull.



Note.—The sinuses coloured dark blue have been thrown open, but in those coloured a paler shade of blue the dura mater has been left undisturbed.

vein. The two sinuses also communicate with each other by means of the anterior and posterior intercavernous sinuses and the network of the basilar plexus.

The expulsion of blood from the cavernous sinus is due mainly to the expansile pulsation of the internal carotid artery in its interior. It is also influenced to some extent by gravity and the position of the head.

The **sphenoparietal sinuses** (fig. 760) run on the under surfaces of the lesser wings of the sphenoid bone, near their posterior edges. Each sinus receives some small veins from the adjacent part of the dura mater and may receive one of the middle meningeal sinuses; it opens into the anterior part of the cavernous sinus.

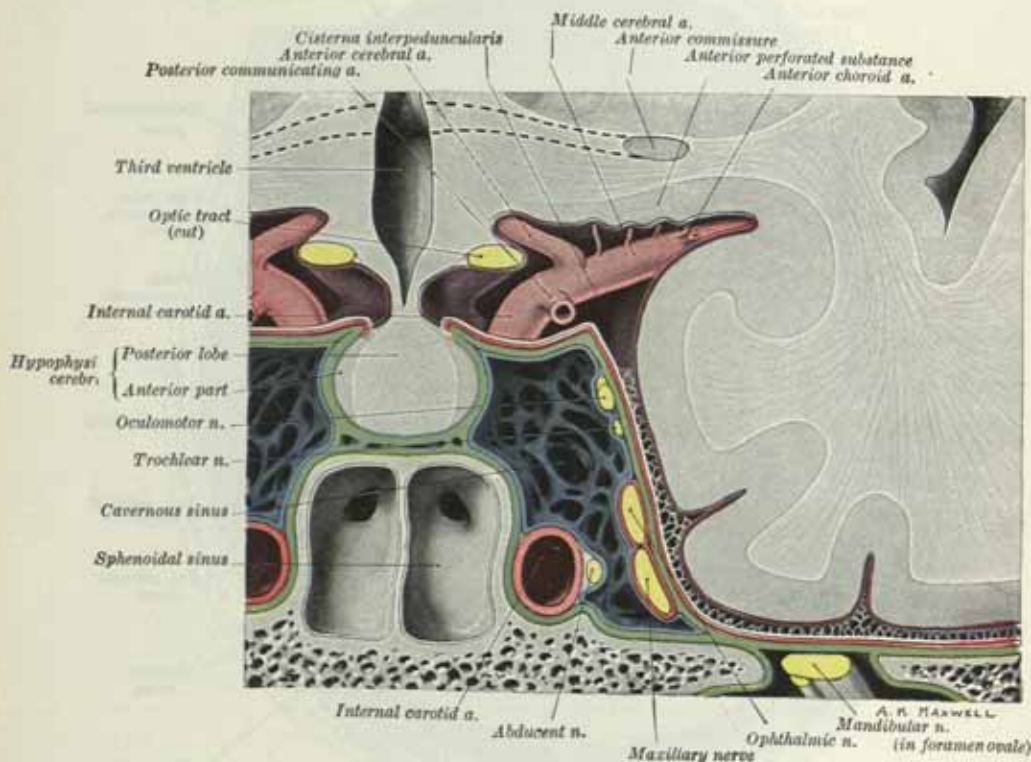
Applied Anatomy.—An arteriovenous communication may be established between the cavernous sinus and the internal carotid artery, giving rise to a pulsating tumour

in the orbit. Such communication may be the result of a bullet wound, a stab, or a blow or fall sufficiently severe to cause a fracture of the base of the skull in this situation. Ligation of the internal or common carotid artery has been performed in these cases with considerable success.

It is now well known that caries in the upper parts of the nasal cavities and suppuration in certain of the accessory sinuses of the nose are frequently responsible for septic thrombosis of the cavernous sinuses, in exactly the same way as thrombosis of the sigmoid sinus is due to septic disease in the mastoid process. Some cases of meningitis are due to the spread of an infection from the ethmoidal or sphenoidal sinuses to the cavernous sinuses, and thence to the meninges.

The **ophthalmic veins** (fig. 762), two in number, superior and inferior, are devoid of valves.

FIG. 761.—An obliquely coronal section through the middle cranial fossa. The ophthalmic and maxillary nerves are shown surrounded by the forward extension of the *cavum trigeminale* (p. 1081).



Pia mater=mauve; Arachnoid mater=white; fibrous layer of dura mater=green; mesothelium of dura mater=red; endothelium of cavernous sinus=light blue.

The **superior ophthalmic vein** begins behind the medial angle of the upper eyelid by the union of two branches which communicate anteriorly with the facial and supra-orbital veins (p. 839). It runs with the ophthalmic artery, receives tributaries corresponding to the branches of that vessel, passes through the medial part of the superior orbital fissure, and ends in the cavernous sinus.

The **inferior ophthalmic vein** begins in a venous network at the fore part of the floor and medial wall of the orbit; it receives some veins from the Rectus inferior, Obliquus inferior, lacrimal sac and eyelids, and runs backwards above the Rectus inferior. It frequently joins the superior ophthalmic vein, but may open into the cavernous sinus. It communicates with the pterygoid venous plexus by means of small veins which pass through the inferior orbital fissure.

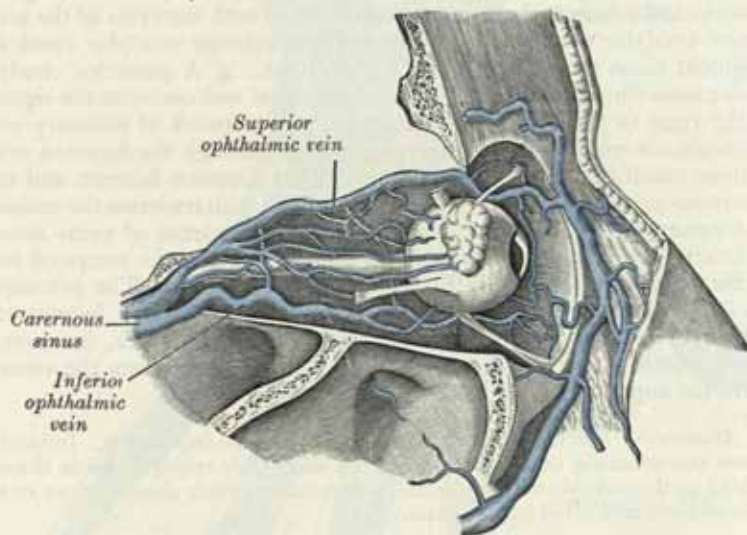
The **intercavernous sinuses**, an anterior and a posterior, connect the cavernous sinuses across the median plane, and are situated in the anterior and posterior attached borders of the diaphragma sellæ; they form with the cavernous sinuses a venous circle (*circular sinus*) (fig. 760). The small, irregular venous sinuses which lie below the hypophysis cerebri drain into the intercavernous sinuses.

The **superior petrosal sinuses** (fig. 760), small and narrow, drain the cavernous sinuses into the transverse sinuses. After leaving the posterosuperior part of the cavernous sinus, each superior petrosal sinus runs backwards and laterally in the attached margin of the tentorium cerebelli. In its course it crosses above the trigeminal nerve and then lies in a groove on the superior border of the petrous part of the temporal bone. Finally, it terminates by joining the transverse sinus where the latter curves downwards to become continuous with the sigmoid sinus. It receives some cerebellar and inferior cerebral veins, and veins from the tympanic cavity.

The **inferior petrosal sinuses** drain the cavernous sinuses into the internal jugular vein. Each (fig. 760) begins in the postero-inferior part of the corresponding cavernous sinus, runs backwards in the groove between the petrous part of the temporal bone and the basilar part of the occipital bone, and, passing through the anterior part of the jugular foramen, ends in the superior bulb of the internal jugular vein. It receives the labyrinthine (internal auditory) veins and also veins from the medulla oblongata, pons, and under surface of the cerebellum.

The relations of the structures transmitted through the jugular foramen are as follows: the inferior petrosal sinus lies medially and anteriorly with the meningeal

FIG. 762.—The veins of the orbit. (Poirier and Charpy.)



branch of the ascending pharyngeal artery, and is directed obliquely downwards and backwards; the sigmoid sinus is situated at the lateral and posterior part of the foramen with a meningeal branch of the occipital artery; between the two sinuses are the glossopharyngeal, vagus, and accessory nerves. The junction of the inferior petrosal sinus with the internal jugular vein usually takes place on the lateral aspect of the nerves.

The **basilar venous plexus** (fig. 760) consists of several interconnecting venous channels situated between the layers of the dura mater over the dorsum sellæ of the sphenoid bone and the basilar part of the occipital bone; it connects the two inferior petrosal sinuses, and communicates with the internal vertebral venous plexus.

The **middle meningeal sinuses** (fig. 760) communicate above with the superior sagittal sinus through the adjoining venous lacunæ, and unite to form two principal trunks, an anterior and a posterior, which accompany the branches of the middle meningeal arteries more or less closely in the grooves on the inner surface of the parietal bone; sometimes they occupy grooves apart from the arteries. Their mode of ending is subject to some variation. The posterior trunk may leave the cranial cavity through the foramen spinosum and open into the pterygoid plexus. The anterior trunk may reach the pterygoid plexus by emerging through the foramen ovale, or it may end in the sphenoparietal sinus or in the cavernous sinus. Besides their meningeal tributaries they receive some small inferior cerebral veins, and communicate with the diploic veins and with the superficial middle cerebral vein.

Wood Jones * has pointed out that the grooves on the inner surfaces of the parietal bones are in reality impressed by the middle meningeal sinuses and not by the arteries, and says, "the vascular tunnel at the pterion, although it lodges arterial branches, is typically formed by, and typically lodges a venous sinus."

Surface Anatomy of the Venous Sinuses.—The *superior sagittal sinus* runs from the glabella to theinion. Narrow anteriorly, it widens as it passes backwards until, near its termination, it is about 1 cm. wide. The *transverse sinus* begins at theinion and runs laterally, with a slight upward convexity to the base of the mastoid process. Here, it is continuous with the *sigmoid sinus* which passes downwards just in front of the posterior border of the mastoid process to a point about 1 cm. from its tip. The sinuses are usually a little more than 1 cm. wide (fig. 754).

THE EMISSARY VEINS

The **emissary veins** pass through apertures in the cranial wall and establish communications between the venous sinuses inside the skull and the veins external to it. Some are constant, but others are not always present. 1. A mastoid emissary vein runs through the mastoid foramen and unites the sigmoid sinus with the posterior auricular or occipital vein. 2. A parietal emissary vein passes through the parietal foramen and connects the superior sagittal sinus with the veins of the scalp. 3. An anterior condylar emissary vein traverses the anterior condylar canal and joins the sigmoid sinus with the internal jugular vein. 4. A posterior condylar emissary vein passes through the posterior condylar canal and connects the sigmoid sinus with the veins in the suboccipital triangle. 5. A network of emissary veins unites the cavernous sinus with the pterygoid plexus through the foramen ovale. 6. Two or three small emissary veins run through the foramen lacerum and connect the cavernous sinus with the pterygoid plexus. 7. A vein traverses the emissary sphenoidal foramen and connects the same vessels. 8. A plexus of veins accompanies the internal carotid artery through the carotid canal of the temporal bone and unites the cavernous sinus with the internal jugular vein. 9. The petrosquamous sinus (p. 849) connects the transverse sinus with the external jugular vein. 10. An emissary vein may pass through the foramen cæcum, which, however, is patent in only a little over 1 per cent. of adult skulls,† and connects the veins of the nose with the superior sagittal sinus.

Applied Anatomy.—The emissary veins are of importance in surgery. Inflammatory processes commencing on the outside of the skull may travel inwards through them, and lead to thrombosis of the sinuses, a condition which always gives rise to considerable anxiety and often proves fatal.

THE VEINS OF THE UPPER LIMB AND THORAX

The veins of the upper limb are divided into two sets, *superficial* and *deep*, which anastomose freely with each other. The superficial veins are placed immediately under the skin, in the superficial fascia; the deep veins accompany the arteries. Both sets are provided with valves, which are more numerous in the deep than in the superficial veins.

THE SUPERFICIAL VEINS OF THE UPPER EXTREMITY (figs. 763, 764)

The **superficial veins** of the upper limb are the cephalic, basilic, and median antibrachial veins, and their tributaries.

The *dorsal digital veins* pass along the sides of the fingers and are joined to one another by oblique communicating branches. Those from the adjacent sides of the fingers unite to form three *dorsal metacarpal veins* (fig. 763), which end in a *dorsal venous network* opposite the middle of the metacarpus. The radial part of the network is joined by the dorsal digital vein from the radial side of the index finger and by the dorsal digital veins of the thumb, and is prolonged proximally as the cephalic vein. The ulnar part of the network receives the dorsal digital vein of the ulnar side

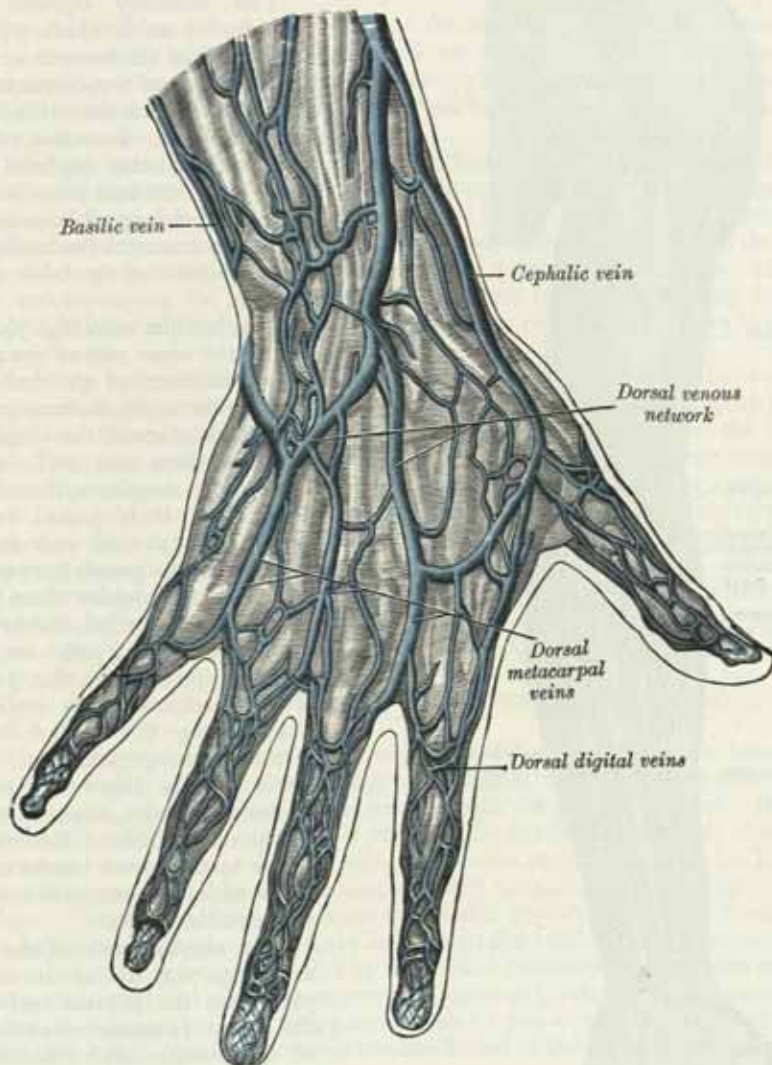
* *J. Anat. and Physiol.*, 46, 1911.

† G. I. Boyd, *J. Anat.*, 65, 1930.

of the little finger and is continued upwards as the basilic vein. A communicating branch frequently connects the dorsal venous network with the cephalic vein about the middle of the forearm.

The *palmar digital veins* are connected to the dorsal digital veins by oblique *intercapitular veins*, which pass backwards between the heads of the metacarpal bones. They also drain into a venous plexus which lies superficial to the palmar aponeurosis, and extends over the thenar and hypothenar eminences.

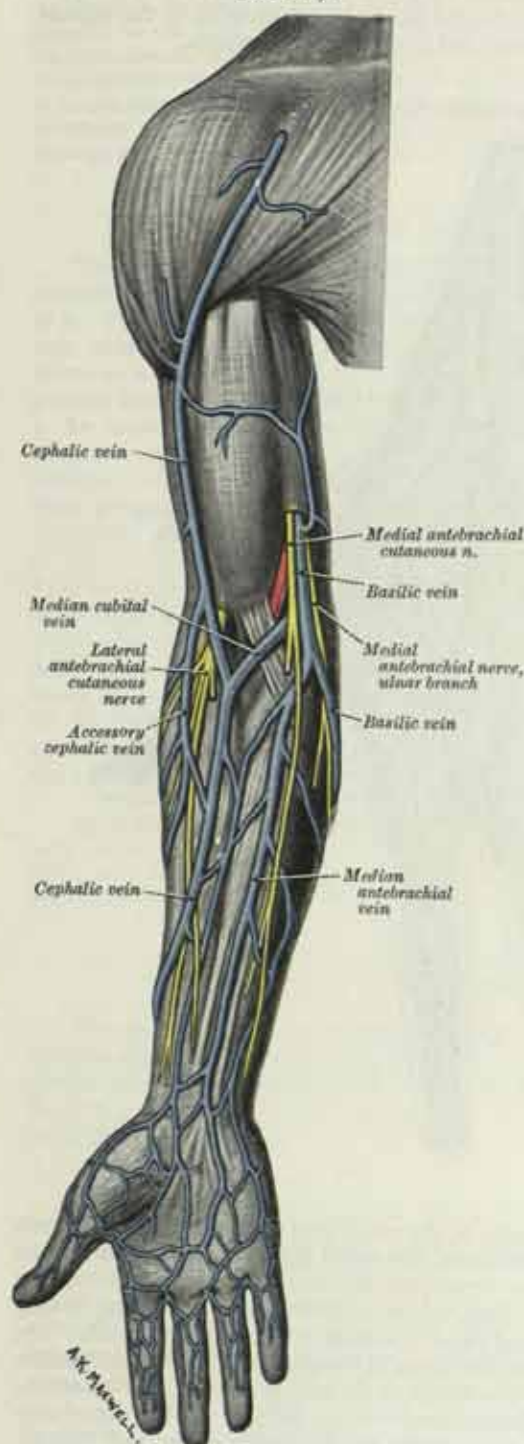
FIG. 763.—The veins of the dorsum of the hand. (Bourguery.)



The **cephalic vein** (fig. 764) begins in the radial part of the dorsal venous network of the hand and winds upwards round the radial border of the forearm to its anterior surface, receiving tributaries from both surfaces. Below the front of the elbow it gives off the *median cubital vein*, which receives a communicating branch from the deep veins of the forearm and passes medially to join the basilic vein. The cephalic vein then ascends in front of the elbow in the groove between the Brachioradialis and the Biceps. It crosses superficial to the lateral antebrachial cutaneous nerve and runs upwards along the lateral border of the Biceps. In the upper one-third of the arm it lies in the interval between the Pectoralis major and Deltoid, where it is accompanied by the deltoid branch of the thoraco-acromial artery. Entering the infraclavicular fossa, it passes under cover of the clavicular head of the Pectoralis major. It then pierces the clavipectoral fascia, crosses the axillary artery,

and ends in the axillary vein just below the clavicle. Sometimes it communicates with the external jugular vein by a branch which ascends in front of the clavicle.

FIG. 764.—The superficial veins of the right upper extremity.



In some cases the median cubital vein is large and carries all or most of the blood from the cephalic into the basilic vein, the result being that the proximal half of the cephalic vein is either absent or of small size.

The *accessory cephalic vein* arises from a small tributary plexus on the back of the forearm or from the ulnar side of the dorsal venous network; it joins the cephalic below the elbow. In some cases it springs from the cephalic vein above the wrist and joins it again higher up. A large oblique branch frequently connects the basilic and cephalic veins on the back of the forearm.

The **basilic vein** (fig. 764) begins in the ulnar part of the dorsal venous network of the hand. It runs up for some distance on the posterior surface of the ulnar side of the forearm but inclines forward to the anterior surface below the elbow. It is joined by the median cubital vein and ascends obliquely in the groove between the Biceps and Pronator teres; filaments of the medial antebrachial cutaneous nerve pass both in front of and behind this portion of the vein. It then runs upwards along the medial border of the Biceps, perforates the deep fascia a little below the middle of the upper arm, and, ascending on the medial side of the brachial artery to the lower border of the Teres major, is continued onwards as the axillary vein.

The **median vein of the forearm** (fig. 764) drains the venous plexus on the palmar surface of the hand. It ascends on the front of the forearm and ends in the basilic vein or the median cubital vein; in a small proportion of cases it divides below the elbow into two branches, one of which joins the basilic vein, the other the cephalic vein.

Surface Anatomy.—All the superficial veins can be seen, especially in spare individuals, up to the points where they pierce the deep fascia. To make them more obvious the fist clenched and relaxed a few

limb should be held in a dependent position and times so that the veins fill with blood.

Applied Anatomy.—*Venesection and intravenous infusion and transfusion* are generally performed at the bend of the elbow, and the largest vein in this situation, usually the median cubital, is commonly selected. Recently the cubital veins have been used for the introduction of cardiac catheters for obtaining samples for blood analysis from the chambers of the heart and the great vessels near the heart. The procedure is easier when the catheter is passed along the left basilic vein, and the head should be approximated to the left shoulder to make the angle of junction of the jugular and subclavian veins more acute.*

THE DEEP VEINS OF THE UPPER LIMB

The **deep veins** follow the course of the arteries as their *venæ comitantes*. They are generally arranged in pairs, and are situated one on each side of the corresponding artery, and connected at intervals by short transverse branches. As most of the blood which supplies the upper limb is returned by the superficial veins, the deep veins are small and inconspicuous.

The deep veins of the hand.—The superficial and deep palmar arterial arches are each accompanied by a pair of *venæ comitantes*, which constitute respectively the *superficial* and *deep palmar venous arches*, and receive the veins corresponding to the branches of the arterial arches; thus the *palmar digital veins* open into the superficial, and the *palmar metacarpal veins* into the deep, palmar venous arches. The deep veins accompanying the dorsal metacarpal arteries receive perforating branches from the palmar metacarpal veins, and end in the radial veins and in the dorsal venous network.

The **deep veins of the forearm** are the *venæ comitantes* of the radial and ulnar arteries and constitute respectively the upward continuations of the deep and superficial palmar venous arches; they unite in front of the elbow to form the brachial veins. The radial veins are smaller than the ulnar, and receive the deep veins of the dorsum of the hand. The ulnar veins receive tributaries from the deep palmar venous arch and communicate with the superficial veins at the wrist; near the elbow they receive the anterior and posterior interosseous veins and send a large communicating branch to the median cubital vein.

The **brachial veins** are placed one on each side of the brachial artery, and receive tributaries corresponding with the branches of that artery; near the lower margin of the Subscapularis, they join the axillary vein; the medial one frequently joins the basilic vein.

These deep veins have numerous anastomoses, not only with each other, but also with the superficial veins.

The **axillary vein** begins at the lower border of the Teres major, as the continuation of the basilic vein, increases in size as it ascends, and ends at the outer border of the first rib, where it becomes continuous with the subclavian vein. Near the lower border of the Subscapularis it receives the brachial veins and, close to its termination, the cephalic vein; its other tributaries correspond with the branches of the axillary artery. It lies on the medial side of the axillary artery, which it partly overlaps; between the two vessels are the medial pectoral nerve, the medial cord of the brachial plexus, the ulnar nerve and the medial antebrachial cutaneous nerve. On its medial side it is accompanied by the medial cutaneous nerve of the arm, and both on its medial and posterior aspects it is intimately related to the lateral group of the axillary lymph nodes. It is provided with a pair of valves opposite the lower border of the Subscapularis; valves are also found in the ends of the cephalic and subscapular veins.

The **subclavian vein** (fig. 704), which is the continuation of the axillary vein, extends from the outer border of the first rib to the medial border of the Scalenus anterior, where it unites with the internal jugular vein to form the brachiocephalic (innominate) vein. It is in relation, in front, with the clavicle and Subclavius; behind and above, with the subclavian artery, from which it is separated by the Scalenus anterior and, on the right side, by the phrenic nerve. Below, it rests in a shallow groove on the first rib and upon the pleura. It is usually provided with a pair of valves, which are situated about 2 cm. from its termination.

Its tributaries are the external jugular vein, sometimes the anterior jugular vein, and occasionally a small branch, which ascends in front of the clavicle, from the cephalic vein.

* Holling, H. E. and Lak, G. A., *Brit. Heart J.*, vol. xii, No. 2, 153, 1950.

At its angle of junction with the internal jugular vein, the left subclavian vein receives the thoracic duct, and the right subclavian vein the right lymphatic duct.

Surface Anatomy.—The deep veins follow the course of the arteries except for the axillary and subclavian veins which lie medial to and below the corresponding arteries. The subclavian vein can be represented by a broad line behind the clavicle from a little medial to its mid-point to the medial edge of the clavicular head of the sternomastoid muscle (fig. 765).

THE VEINS OF THE THORAX (figs. 765 to 767)

The **brachiocephalic (innominate) veins** are two large trunks, placed in the root of the neck and in the uppermost part of the thorax; each is formed by the union of the internal jugular and subclavian veins of the corresponding side and both are devoid of valves.

The **right brachiocephalic vein** (fig. 765), about 2.5 cm. long, begins behind the sternal end of the right clavicle, and, passing almost vertically downwards, joins the left brachiocephalic vein to form the superior vena cava behind the lower border of the cartilage of the first rib, close to the right border of the sternum. It lies in front and to the right of the brachiocephalic artery and the right vagus nerve. The right pleura, phrenic nerve, and internal thoracic artery are posterior to the upper part, and lateral to the lower part of the vein.

Its tributaries are the right vertebral, the right internal thoracic and the right inferior thyroid veins, and sometimes the first right posterior intercostal vein.

The **left brachiocephalic vein** (fig. 765), about 6 cm. long, begins behind the sternal end of the left clavicle, where it lies in front of the left cervical pleura. It runs obliquely downwards and to the right behind the upper half of the manubrium sterni to the sternal end of the first right costal cartilage, where it unites with the right brachiocephalic vein to form the superior vena cava. It is separated from the left sternoclavicular joint and the manubrium sterni by the Sternohyoid and Sternothyroid, the thymus or its remains, and some loose areolar tissue, and, at its termination, is overlapped by the right pleura. In its course it crosses superficial to the left internal thoracic, subclavian and common carotid arteries, the left phrenic and vagus nerves, the trachea and the brachiocephalic artery. The arch of the aorta lies below the vessel.

Its tributaries are the left vertebral, left internal thoracic, left inferior thyroid, and left superior intercostal veins, sometimes the first left posterior intercostal vein and occasionally some thymic and pericardial veins.

Surface Anatomy.—The brachiocephalic veins can be represented by broad bands 1.5 cm. wide from the sternal end of the clavicle on each side to the formation of the superior vena cava at the lower border of the first right costal cartilage.

Peculiarities.—Sometimes the brachiocephalic veins open separately into the right atrium: in such cases the right vein takes the ordinary course of the superior vena cava the left vein—*left superior vena cava*, as it is then termed—which may communicate by a small branch with the right one, crosses the left side of the arch of the aorta, passes in front of the root of the left lung, and, turning to the back of the heart, ends in the right atrium. It replaces the oblique vein of the left atrium and the coronary sinus and receives all the tributaries of the latter vessel. This occasional condition in the adult is due to the persistence of the early foetal condition (p. 175), and is the normal condition in birds and some mammals.

The left brachiocephalic vein sometimes projects above the level of the manubrium sterni, crossing the suprasternal fossa, and lying in front of the trachea.

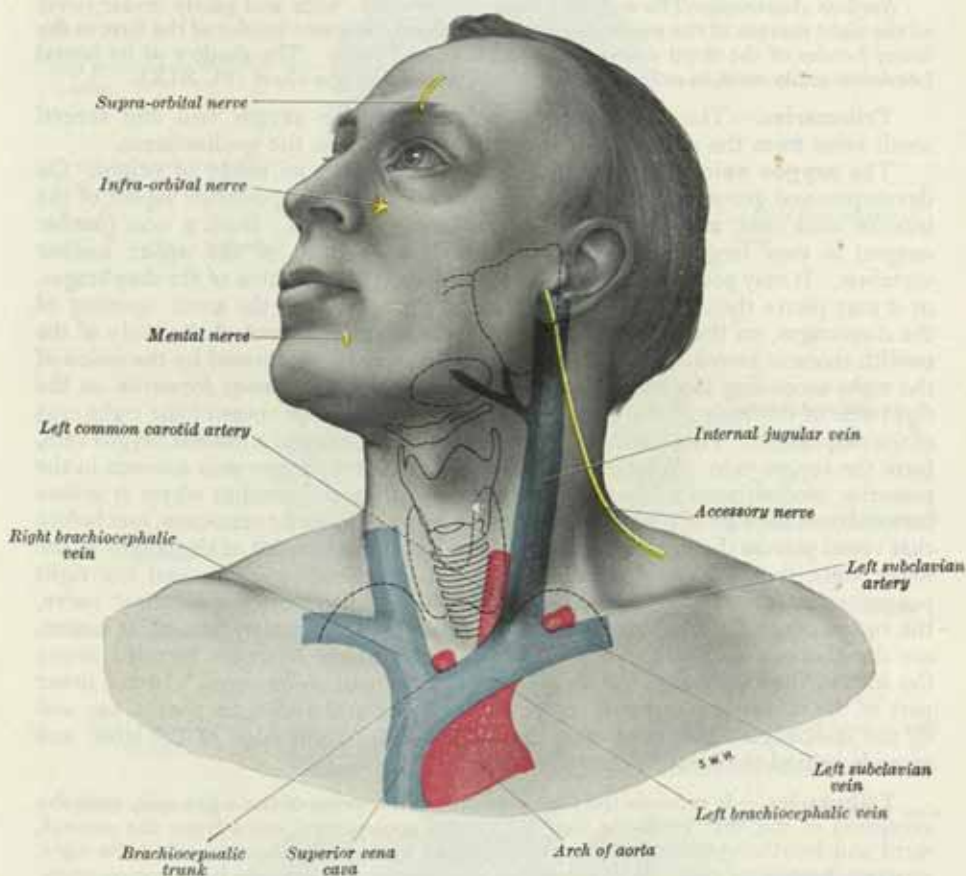
The **internal thoracic (mammary) veins** (figs. 682, 705) are *venae comitantes* to the lower half of the internal mammary artery, and are provided with a number of valves. About the level of the third costal cartilage the *venae comitantes* unite to form a single trunk, which runs up medial to the artery and ends in the corresponding brachiocephalic vein. They receive as tributaries the veins which accompany the branches of the internal thoracic artery (p. 770), and usually the pericardiacophrenic vein.

The **inferior thyroid veins** (fig. 682), two in number, arise in the thyroid gland in a venous network which communicates with the middle and superior thyroid veins. They form a plexus in front of the trachea. From this plexus the left vein descends and joins the left brachiocephalic trunk, and the right vein passes obliquely downwards and to the right across the brachiocephalic artery to open into

the right brachiocephalic vein, at its junction with the superior vena cava; frequently the two veins open by a common trunk either in the latter situation or into the left brachiocephalic vein. These veins receive œsophageal, tracheal, and inferior laryngeal veins, and are provided with valves at their terminations.

The **left superior intercostal vein** (fig. 766) receives the second and third (and sometimes the fourth) left posterior intercostal veins; it runs obliquely upwards and forwards on the left side of the aortic arch, passing lateral to the left vagus and medial to the left phrenic nerve, and opens into the left brachiocephalic vein. It

FIG. 765.—The surface relations of some of the important structures in the face, neck and upper part of thorax.



Note.—The apices of the lungs, the thyroid, submandibular and parotid glands, and the parotid duct are indicated in dotted outline; the hyoid bone, the thyroid and cricoid cartilages and the rings of the trachea are shown in solid black.

usually receives the left bronchial veins, and sometimes the left pericardiacophrenic vein; it communicates below with the superior hemiazygos vein. Occasionally it gives off, near its termination, a small vessel which runs downwards across the aortic arch and behind the left pulmonary artery to enter the ligament of the left vena cava (p. 704). Gaining the dorsal aspect of the left atrium this small vessel becomes continuous with the oblique vein.

The **superior vena cava** (figs. 677, 679, 680, 681, 766) drains the blood from the upper half of the body. It measures about 7 cm. in length, is formed by the junction of the two brachiocephalic veins, and is devoid of valves. It begins behind the lower border of the first right costal cartilage close to the sternum, and, descending vertically behind the first and second intercostal spaces, ends in the upper part of the right atrium opposite the third right costal cartilage; the lower half of the vessel is within the fibrous pericardium, which it pierces at the level of the second costal cartilage. It is covered in front and on each side with the serous

pericardium. In its course it describes a slight curve, the convexity of which is to the right side.

Relations.—*In front*, the superior vena cava is related to the anterior margins of the right lung and pleura with the pericardium intervening below; these separate it from the internal thoracic artery, and the first and second intercostal spaces, and from the second and third costal cartilages; the trachea and the right vagus nerve are *posteromedial* and the right lung and pleura *posterolateral* to its upper part, while the root of the right lung is a direct posterior relation below. On its *right side*, it is related to the right phrenic nerve and right pleura; on its *left side*, to the commencement of the brachiocephalic artery and the ascending aorta, the latter overlapping it.

Surface Anatomy.—The superior vena cava is 2 cm. wide and partly under cover of the right margin of the sternum. It extends from the lower border of the first to the lower border of the third costal cartilage of the right side. The shadow of its lateral border is easily seen in antero-posterior radiographs of the chest (Pl. XIX).

Tributaries.—The superior vena cava receives the azygos vein and several small veins from the pericardium and other structures in the mediastinum.

The **azygos vein*** (figs. 766, 767) is inconstant in its mode of origin. On developmental grounds it may be expected to arise from the posterior aspect of the inferior vena cava, at or below the level of the renal veins. Such a vein (*lumbar azygos*) is very frequently present and ascends in front of the upper lumbar vertebræ. It may pass deep to the lateral border of the right crus of the diaphragm, or it may pierce the crus. Occasionally it may pass through the aortic opening of the diaphragm, on the right side of the cisterna chyli. In front of the body of the twelfth thoracic vertebra, it is joined by a large vessel which, formed by the union of the right ascending lumbar with the right subcostal vein, passes forwards on the right side of the body of the twelfth thoracic vertebra under cover of the right crus of the diaphragm. This common trunk may, in the absence of a lumbar azygos vein, form the azygos vein. Whatever its mode of origin, the azygos vein ascends in the posterior mediastinum to the level of the fourth thoracic vertebra where it arches forward over the root of the right lung, and ends in the superior vena cava, just before that vessel pierces the pericardium. In its course it lies in front of the bodies of the lower eight thoracic vertebræ, the anterior longitudinal ligament, and the right posterior intercostal arteries. On its right side are the greater splanchnic nerve, the right lung and pleura; on its left side, throughout the greater part of its course, are the thoracic duct and aorta, and higher up, where it arches forward above the root of the right lung, the œsophagus, trachea and right vagus. In the lower part of the thorax it is covered anteriorly by a recess of the right pleural sac and by the œsophagus, but it emerges from behind the right edge of the latter and ascends behind the hilus of the right lung (fig. 767).

Tributaries.—It receives the posterior intercostal veins of the right side, with the exception of the vein from the first intercostal space; the veins from the second, third and fourth intercostal spaces usually open by a common stem called the right superior intercostal vein. It receives also the superior and inferior hemiazygos veins, several œsophageal, mediastinal, and pericardial veins, and, near its termination, the right bronchial veins. When it begins as a lumbar azygos vein, the common trunk formed by the union of the right ascending lumbar and subcostal veins is its largest tributary. A few imperfect valves are found in the azygos vein, but its tributaries are provided with complete valves.

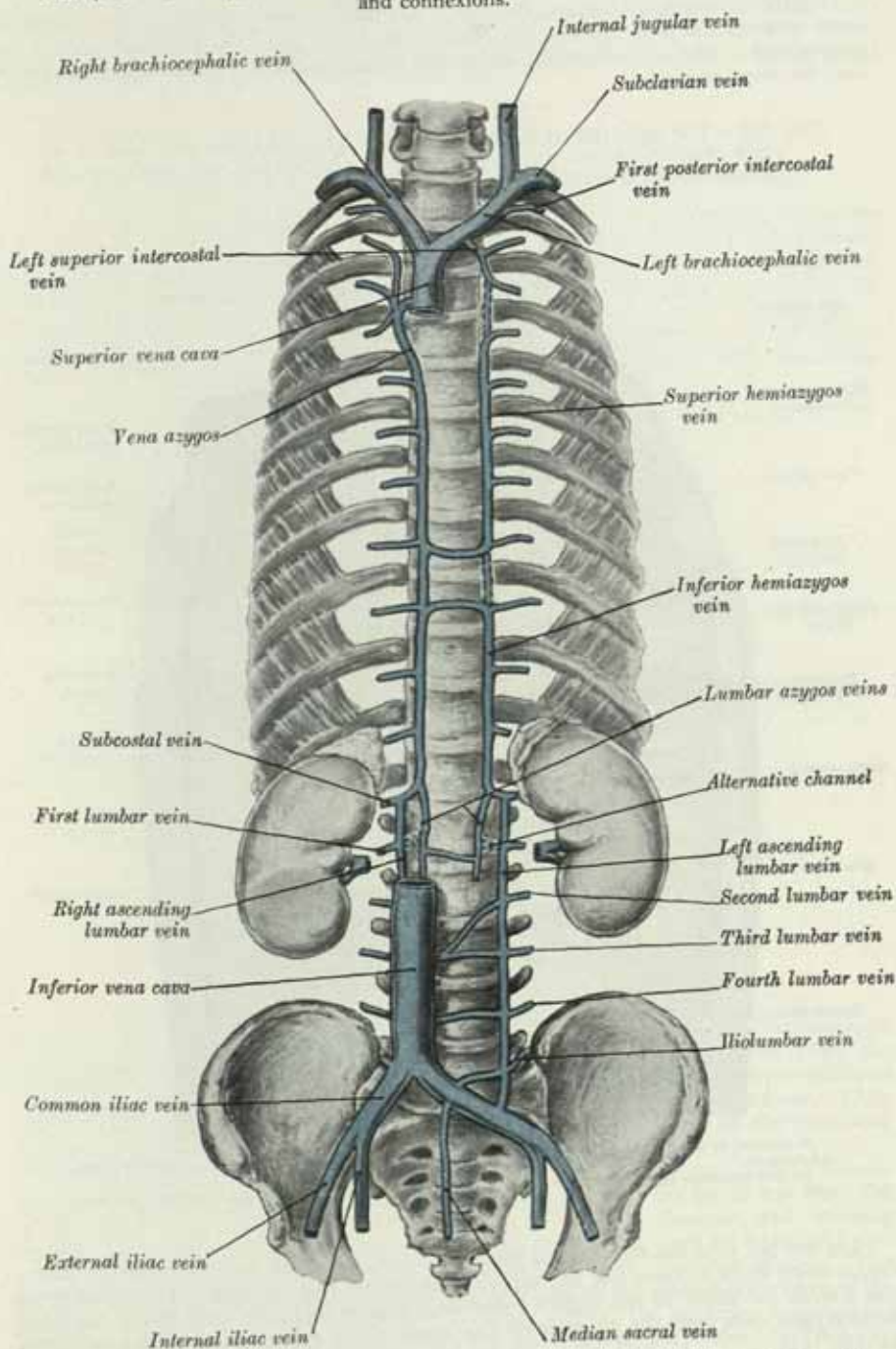
The **inferior hemiazygos vein** (fig. 766) arises on the left side in a manner corresponding to the origin of the azygos vein on the right side and, ascending on the front of the vertebral column as high as the eighth thoracic vertebra, passes across the column, behind the aorta, œsophagus, and thoracic duct, to end in the azygos vein. It receives the lower three posterior intercostal veins and the common trunk formed by the union of the ascending lumbar and the subcostal veins of the left side, and some œsophageal and mediastinal veins. Its lower end often communicates with the left renal vein.

The **superior hemiazygos vein** (fig. 766) descends on the left side of the vertebral column. It receives the veins from the fourth (or fifth) to the eighth intercostal spaces inclusive of the left side, and sometimes the left bronchial veins. It crosses the body of the seventh thoracic vertebra and joins the azygos vein. The superior hemiazygos

* The arrangement of the rootlets of the azygos and hemiazygos veins is subject to a wide range of variation. See R. J. Gladstone, *J. Anat.* 64, 1929.

vein sometimes joins the inferior hemiazygos vein, and the common trunk thus formed opens into the azygos vein.

FIG. 766.—The azygos, hemiazygos and ascending lumbar veins, their tributaries and connexions.



N.B.—On both sides the first lumbar vein is shown terminating in the ascending lumbar vein, but its occasional termination in the lumbar azygos vein is indicated as well.
Both hemiazygos veins cross the median plane one vertebra lower than usual.

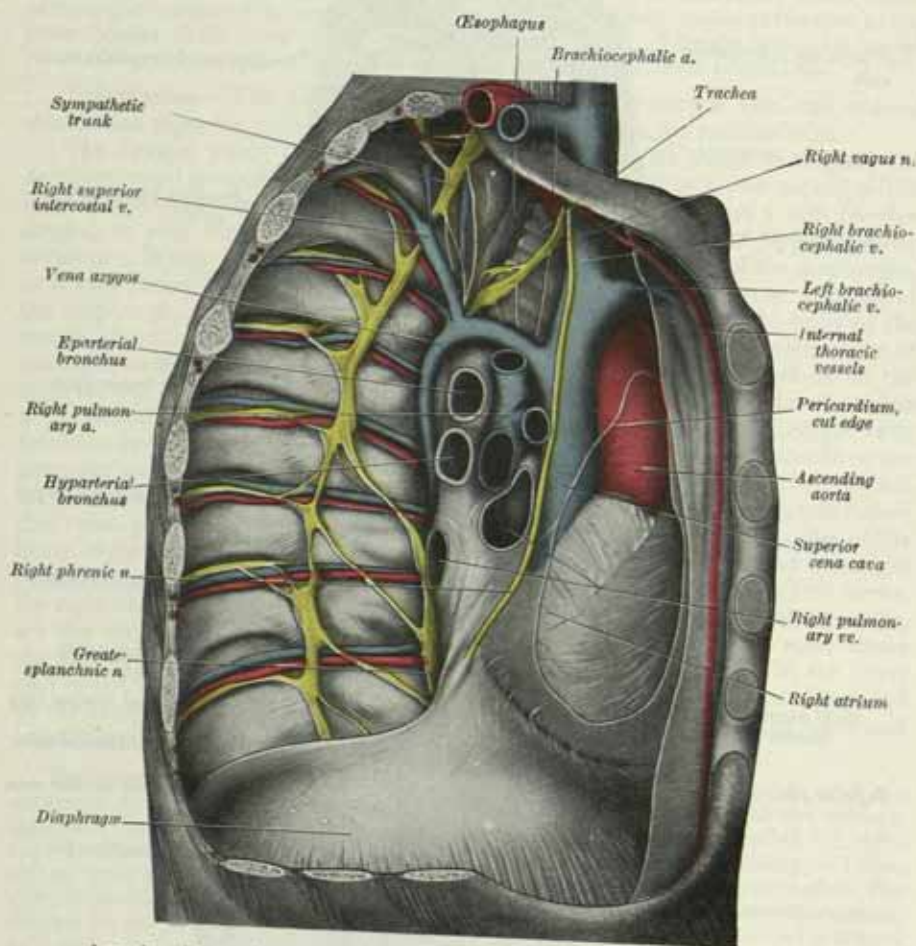
The **posterior intercostal veins** (figs. 721, 766, 767) run with the posterior intercostal arteries and are eleven in number on each side. As they approach the vertebral column each vein receives a tributary which accompanies the posterior branch of the

corresponding artery and returns blood from the muscles and skin of the back and from the vertebral venous plexuses.

On both sides of the thorax the first posterior intercostal vein ascends in front of the neck of the first rib and, arching forwards above the pleura, ends in the corresponding brachiocephalic or vertebral vein.

On the right side the second, third and, often, the fourth posterior intercostal veins unite to form the *right superior intercostal vein*, which joins the terminal part of the azygos vein. The veins from the intercostal spaces below the fourth open separately into the *vena azygos*.

FIG. 767.—The right side of the mediastinum. The right lung and most of the right pleura have been removed and a large opening has been made into the pericardial sac to expose the heart.



A portion of the pericardial sac has been removed in order to expose the lateral aspect of the right atrium.
In this specimen the fourth right posterior intercostal vein did not join the superior intercostal vein.

On the left side the second and third (and sometimes the fourth) posterior intercostal veins unite to form the left superior intercostal vein (p. 859). The veins from the fourth (or fifth) to the eighth intercostal spaces inclusive end in the superior hemiazygos vein, and the veins from the lower three spaces in the inferior hemiazygos vein.

The posterior intercostal veins are called 'posterior' to distinguish them from the small *anterior intercostal veins*, which are tributaries of the internal thoracic and musculophrenic veins.

Applied Anatomy.—In obstruction of the *venæ cavæ*, the azygos and hemiazygos veins are one of the principal means by which the venous circulation is carried on, connecting, as they do, the superior and inferior *venæ cavæ*, and communicating

with the common iliac veins by the ascending lumbar veins, and with many of the tributaries of the inferior vena cava.

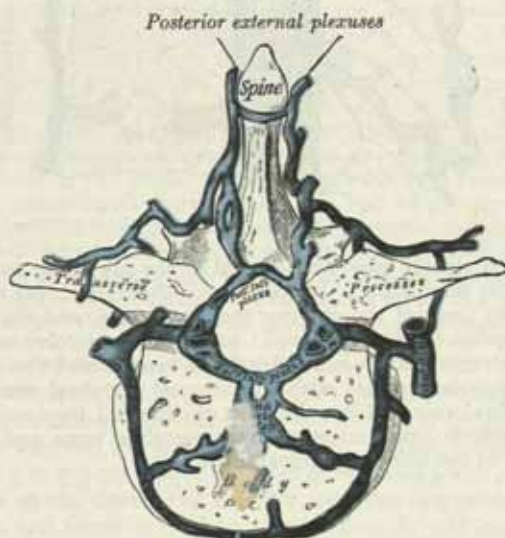
The **bronchial veins**, usually two on each side, return the blood from the larger bronchi, and from the structures at the roots of the lungs. The bronchial veins of the right side open into the terminal part of the vena azygos; those of the left side, into the left superior intercostal vein or the superior hemiazygos vein. Some of the blood carried to the lungs through the bronchial arteries is returned to the heart through the pulmonary veins.

THE VEINS OF THE VERTEBRAL COLUMN (figs. 768, 769)

The veins of the vertebral column form intricate plexuses extending along the entire length of the column; these plexuses are divisible into two groups, termed external and internal, according to their positions outside or inside the vertebral canal. The plexuses of the two groups anastomose freely with each other, and end in the intervertebral veins.

The **external vertebral venous plexuses**, best marked in the cervical region, consist of anterior and posterior plexuses, which anastomose freely with each other.

FIG. 768.—A transverse section through a thoracic vertebra, showing the vertebral venous plexuses.



The *anterior external plexuses* lie in front of the bodies of the vertebrae, communicate with the basi-vertebral and intervertebral veins, and receive tributaries from the vertebral bodies. The *posterior external plexuses* are placed on the posterior surfaces of the laminae and around the spines and the transverse and articular processes. They anastomose with the internal vertebral venous plexuses, and end in the vertebral, posterior intercostal and lumbar veins.

The **internal vertebral venous plexuses** lie within the vertebral canal between the dura mater and the vertebrae, and receive tributaries from the bones and from the spinal cord. They form a closer network than the external plexuses, and, running mainly in a vertical direction, form four longitudinal veins, two in front and two behind; they therefore may be divided into anterior and posterior groups. The *anterior internal plexuses* consist of large veins which lie on the posterior surfaces of the vertebral bodies and intervertebral discs, on each side of the posterior longitudinal ligament; under cover of this ligament they are connected by transverse branches into which the basivertebral veins open. The *posterior internal plexuses* are placed one on each side of the median plane in front of the vertebral arches and ligamenta flava, and anastomose, by veins passing through those ligaments, with the posterior external plexuses.

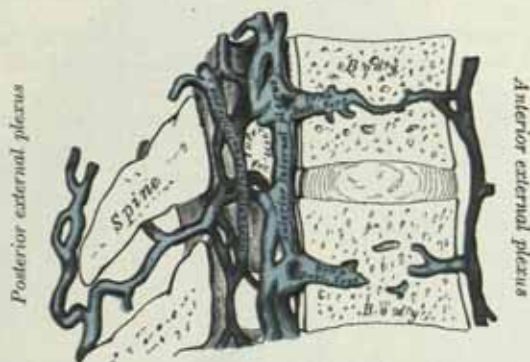
The anterior and posterior internal plexuses communicate freely with one another by a series of venous rings, one opposite each vertebra. Around the foramen magnum they form an intricate network, which opens into the vertebral veins and is connected

above with the occipital and sigmoid sinuses, the basilar plexus, and with the anterior and posterior condylar emissary veins.

The **basivertebral veins** emerge from the foramina on the posterior surfaces of the vertebral bodies. They are contained in large, tortuous channels in the substance of the bones, similar in every respect to those found in the diploë of the cranial bones. They communicate with the anterior external vertebral plexuses through small openings on the front and sides of the bodies of the vertebræ, and converge behind to form single (sometimes double) veins, which open by valved orifices into the transverse branches uniting the anterior internal vertebral plexuses. The basivertebral veins become enlarged in advanced age.

The **intervertebral veins** accompany the spinal nerves through the intervertebral foramina; they receive veins from the spinal cord, drain the internal and external vertebral plexuses and end in the vertebral, posterior intercostal, lumbar and lateral sacral veins, their orifices being provided with valves.

FIG. 769.—A median sagittal section through two thoracic vertebræ, showing the vertebral venous plexuses.



The **veins of the spinal cord** are situated in the pia mater and form a tortuous venous plexus in this membrane. In this plexus there are: (a) two median longitudinal veins, one in front of the anterior median fissure, and the other behind the posterior median septum of the spinal cord; and (b) two anterolateral and two posterolateral longitudinal veins, which run behind the ventral and the dorsal nerve-roots respectively. They communicate with the internal vertebral venous plexuses, and with the intervertebral veins. Near the base of the skull they unite to form two or three small trunks, which communicate with the vertebral veins, and end in the inferior cerebellar veins, or in the inferior petrosal sinuses.

THE VEINS OF THE LOWER LIMB, ABDOMEN AND PELVIS

The veins of the lower limb are subdivided, like those of the upper limb, into two sets, *superficial* and *deep*: the superficial veins are placed immediately under the skin in the superficial fascia; the deep veins accompany the arteries. Both sets are provided with valves, which are more numerous in the deep than in the superficial veins. Valves are more plentiful in the veins of the lower than in those of the upper limb.

THE SUPERFICIAL VEINS OF THE LOWER LIMB (figs. 770, 771)

The **superficial veins** of the lower limb are the great and small (long and short) saphenous veins and their tributaries.

The **dorsal digital veins** receive, in the clefts between the toes, communications from the plantar digital veins, and then join to form **dorsal metatarsal veins**, which unite across the distal ends of the metatarsal bones in a **dorsal venous arch**. Proximal to this arch there is an irregular dorsal venous network, which receives tributaries from the deep veins and is continuous with the venous network on the front of the leg. At the sides of the foot this network communicates with a **medial** and a **lateral marginal vein**, both of which are formed mainly by the union of veins from the superficial parts of the sole of the foot.

In the sole of the foot the superficial veins form a *plantar cutaneous venous arch*, which extends across the roots of the toes and opens at the sides of the foot into the medial and lateral marginal veins. Proximal to this arch there is a *plantar cutaneous venous network*, which is especially dense in the fat beneath the heel; this network communicates with the plantar cutaneous venous arch and with the deep veins, but is chiefly drained into the medial and lateral marginal veins.

The **great (long) saphenous vein** (fig. 770), the longest vein in the body, begins in the medial marginal vein of the foot, and ends in the femoral vein about 3 cm. below the inguinal ligament. It ascends in front of the tibial malleolus and runs upwards, crossing the medial surface of the tibia obliquely to gain its medial border, along which it ascends to the knee. It runs upwards on the posterior parts of the medial condyles of the tibia and femur and along the medial side of the thigh and, passing through the saphenous opening (p. 656), ends in the femoral vein. In the thigh it is accompanied by some branches of the medial femoral cutaneous nerve, at the knee by the saphenous branch of the descending genicular artery, and in the leg and foot by the saphenous nerve, which is placed in front of the vein. The great saphenous vein is often duplicated, especially below the knee. The valves in it number from ten to twenty and are more numerous in the leg than in the thigh.

Tributaries.—At the ankle it receives veins from the sole of the foot through the medial marginal vein; in the leg it communicates freely with the small saphenous vein and with the anterior and posterior tibial veins, and receives many cutaneous veins; in the thigh it receives numerous tributaries; those from the medial and posterior parts of the thigh frequently unite to form a large *accessory saphenous vein*, which joins the main vein at a variable level. Near the saphenous opening (fig. 770) it is joined by the superficial epigastric, superficial circumflex iliac and external pudendal veins. The superficial epigastric and superficial circumflex iliac veins drain the lower part of the abdominal wall, the latter vein also receiving tributaries from the upper and lateral parts of the thigh; the external pudendal veins drain part of the scrotum and one is joined by the superficial dorsal vein of the penis.

A vein, named the *thoraco-epigastric*, runs along the anterolateral wall of the trunk, connecting the superficial epigastric vein, or the femoral vein, with the lateral thoracic veins and establishing a communication between the femoral and axillary veins. The importance of this communication lies in the fact that it serves as a connecting channel between the superior and the inferior vena caval fields of drainage.

The **small (short) saphenous vein** (fig. 771) begins behind the lateral malleolus as a continuation of the lateral marginal vein of the foot; it first ascends on the lateral border of the tendo calcaneus, and then along the middle of the back of the leg. It perforates the deep fascia in the lower part of the popliteal fossa, and ends in the popliteal vein from 3 to 7.5 cm. above the level of the knee-joint. It communicates with the deep veins on the dorsum of the foot, receives numerous tributaries from the back of the leg, and sends several branches upwards and medially to join the great saphenous vein. In the leg it is in close relation with the sural nerve. The small saphenous vein possesses from seven to thirteen valves, one of which is found near its termination in the popliteal vein.

The mode of ending of the small saphenous vein is subject to considerable variations. It may join the great saphenous vein in the upper one-third of the thigh, or may divide into two branches, one of which joins the great saphenous vein, the other the popliteal vein or the deep posterior veins of the thigh; occasionally it ends, below the level of the knee-joint, in the great saphenous vein or in the deep muscular veins of the calf.*

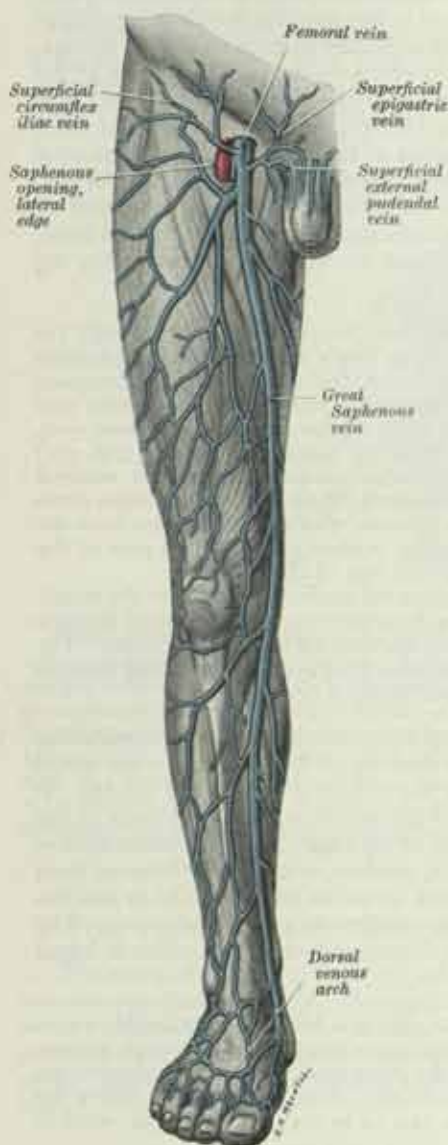
Surface Anatomy.—The superficial veins are usually visible in the leg and foot, but not in the thigh because of the amount of fat in which they are embedded. The *saphenous opening* lies 4 cm. below and lateral to the pubic tubercle and the upper part of the great saphenous vein may be represented by a line from here to the adductor tubercle.

Applied Anatomy.—A varicose condition is more frequently met with in the saphenous veins than in the other veins of the body, except perhaps the testicular and rectal veins. Despite the fact that the normal histology of the vein walls and their valves is not altered, dilatation may take place rendering the valves incompetent. This

* C. Kosinski, *Proc. Anat. Soc.*, 47, 1925.

is true especially of the important communicating veins which connect the superficial and the deep groups, passing through the deep fascia. Since the emptying of the superficial veins depends on the valvular competence of these communicating veins, they appear to hold the key to understanding the cause of primary varicose veins.

FIG. 770.—The great saphenous vein and its tributaries.



THE DEEP VEINS OF THE LOWER LIMB

The **deep veins** of the lower extremity accompany the arteries and their branches; they possess numerous valves.

The **plantar digital veins** arise from plexuses on the plantar surfaces of the digits, and, after sending communications to join the dorsal digital veins, unite to form four **plantar metatarsal veins**; these run backwards in the metatarsal spaces, communicate, by means of perforating veins, with the veins on the dorsum of the foot, and unite to form the **deep plantar venous arch**, which lies alongside the plantar arterial arch. From the deep plantar venous arch the **medial and lateral plantar veins** run backwards close to the corresponding arteries and, after communicating with the great and small saphenous veins, unite behind the medial malleolus to form the posterior tibial veins.

The **posterior tibial veins** accompany the posterior tibial artery, and are joined by the **peroneal veins**.

The **anterior tibial veins** are the upward continuations of the *venæ comitantes* of the *dorsalis pedis* artery. They leave the front of the leg by passing between the tibia and fibula, through the upper part of the interosseous membrane of the leg, and unite with the posterior tibial veins to form the **popliteal vein**.

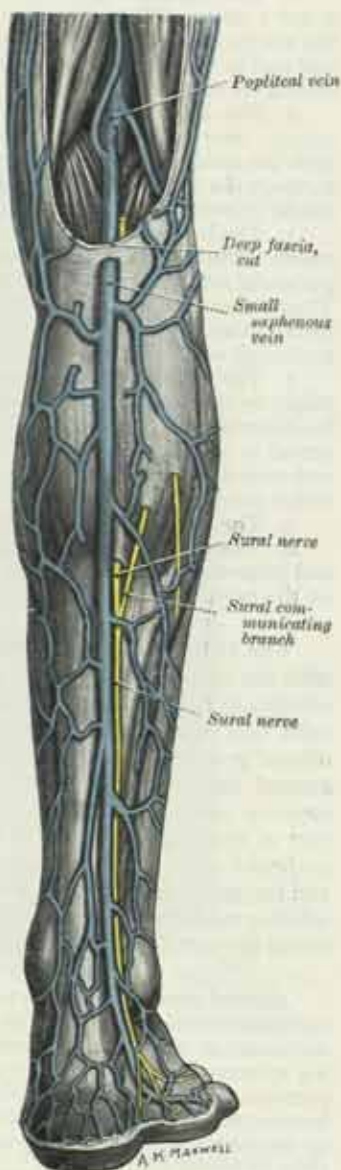
The **popliteal vein**, formed by the junction of the anterior and posterior tibial veins at the lower border of the Popliteus, ascends through the popliteal fossa to the aperture in the Adductor magnus where it becomes the femoral vein. In the lower part of its course it is medial to the popliteal artery; between the heads of the Gastrocnemius it is superficial to it; above the knee-joint it is posterolateral to it. Its tributaries are the small saphenous vein and the veins corresponding to the branches of the popliteal artery. There are usually four valves in the popliteal vein.

The **femoral vein** accompanies the femoral artery, beginning at the opening in the Adductor magnus, as the continuation of the popliteal vein, and ending at the level of the inguinal ligament, by becoming the external iliac vein. In the lower part of the adductor canal it is posterolateral to the femoral artery; in the upper part of the canal, and in the lower part of the femoral triangle, it is behind the artery. At the base of the femoral triangle it is medial to the artery (figs. 737, 740); here it occupies the middle compartment of the femoral sheath, and is placed between the femoral artery and the femoral canal, the fatty tissue in the latter allowing considerable expansion of the vein. It receives numerous muscular tributaries, and about 4 cm. below the inguinal ligament is joined posteriorly by the *vena profunda*

femoris, and a little higher by the great saphenous vein, which enters its anterior aspect. In addition, it usually receives the lateral and medial circumflex femoral veins. A valve, which may be single or double, is placed at the upper end of the femoral vein, and another is usually present above the opening of its profunda femoris tributary.

The *vena profunda femoris* usually lies anterior to the profunda femoris artery; it receives tributaries corresponding to the muscular and perforating branches of that artery, and through these establishes communications with the popliteal vein below and the inferior gluteal vein above. It sometimes receives the medial and lateral circumflex femoral veins.

FIG. 771.—The small saphenous vein.



THE VEINS OF THE ABDOMEN AND PELVIS (figs. 722, 772)

The **external iliac vein**, the upward continuation of the femoral vein, begins behind the inguinal ligament, and ascends along the brim of the lesser pelvis, to a point opposite the sacro-iliac joint, where it unites with the internal iliac vein to form the common iliac vein. On the right side, it lies at first medial to the artery; but, as it passes upwards, gradually inclines behind it. On the left side, it lies altogether on the medial side of the artery. On its medial aspect, it is crossed by the ureter and the internal iliac artery; elsewhere it is covered with peritoneum. In the male it is crossed by the ductus deferens and in the female by the round ligament of the uterus and the ovarian vessels. Laterally it is related to the Psoas major muscle, except where the external iliac artery intervenes. It frequently contains one, sometimes two, valves.

Tributaries.—It receives the inferior epigastric, deep circumflex iliac and pubic veins.

The **inferior epigastric vein** is formed by the union of the *venæ comitantes* of the inferior epigastric artery, which communicate above with the superior epigastric vein; it joins the external iliac vein about 1 cm. above the inguinal ligament.

The **deep circumflex iliac vein** is formed by the union of the *venæ comitantes* of the deep circumflex iliac artery, and joins the external iliac vein about 2 cm. above the inguinal ligament after crossing in front of the external iliac artery.

The **pubic vein**, which connects the external iliac with the obturator vein in the obturator foramen, ascends on the pelvic surface of the pubis alongside the pubic branch of the inferior epigastric artery. It is frequently enlarged and replaces the normal obturator vein.

The **internal iliac vein** begins near the upper part of the greater sciatic foramen, ascends behind and slightly medial to the internal iliac artery, and, at the brim of the pelvis, joins with the external iliac vein to form the common iliac vein. It lies in front of the lower part of the sacro-iliac joint and is covered with peritoneum on its anteromedial aspect.

Tributaries.—With the exception of the ilio-lumbar vein, which usually joins the common iliac vein, the tributaries of the internal iliac vein correspond with the branches of the internal iliac artery. It receives (a) the gluteal, internal pudendal,

and obturator veins, which have their origins outside the pelvis; (b) the lateral sacral veins, which lie in front of the sacrum; and (c) the middle rectal, the vesical, uterine, and vaginal veins, which originate in venous plexuses connected with the pelvic viscera.

1. The **superior gluteal veins** are the *venæ comitantes* of the superior gluteal artery; they receive tributaries from the buttock corresponding with the branches of the artery, enter the pelvis through the greater sciatic foramen, above the Piriformis, and end in the internal iliac vein; they frequently unite to form a single trunk before ending in this vein.

2. The **inferior gluteal veins** are the *venæ comitantes* of the inferior gluteal artery; they begin on the upper part of the back of the thigh, where they anastomose with the medial circumflex femoral and first perforating veins; they enter the pelvis through the lower part of the greater sciatic foramen and join to form a stem which opens into the lower part of the internal iliac vein.

3. The **internal pudendal veins** are the *venæ comitantes* of the internal pudendal artery. They begin in the prostatic venous plexus (*vide infra*), accompany the internal pudendal artery, and unite to form a single vessel, which ends in the internal iliac vein. They receive the veins from the bulb of the penis, and the scrotal or labial and inferior rectal veins. The deep dorsal vein of the penis communicates with the internal pudendal veins, but ends mainly in the prostatic plexus.

4. The **obturator vein** begins in the upper portion of the adductor region of the thigh, and enters the pelvis through the upper part of the obturator foramen. It runs backwards and upwards on the lateral wall of the pelvis below the obturator artery and lateral to the peritoneum; it passes between the ureter and the internal iliac artery, and ends in the internal iliac vein. Sometimes it is replaced by an enlarged pubic vein, which joins the external iliac vein.

5. The **lateral sacral veins** accompany the lateral sacral arteries.

6. The **middle rectal vein** varies in size; it begins in the rectal venous plexus, and receives tributaries from the bladder, prostate and seminal vesicle; it runs laterally on the pelvic surface of the Levator ani and ends in the internal iliac vein.

The **rectal venous plexus** surrounds the rectum, and communicates in front with the vesical plexus in the male, and the uterovaginal plexus in the female. It consists of two parts, an *internal* in the submucosa, and an *external* outside the muscular coat of the rectum and anal canal. The internal plexus presents a series of dilated pouches, connected by transverse branches, which are arranged in a circle around the tube, immediately above the anal orifice. It drains mainly into the superior rectal vein but communicates freely with the external plexus. The lower part of the external plexus is drained by the inferior rectal veins into the internal pudendal vein; the middle part by the middle rectal vein into the internal iliac vein; and the upper part by the superior rectal vein, which forms the commencement of the inferior mesenteric vein, a tributary of the portal vein. A free communication between the portal and systemic venous systems is established through the rectal plexus.

*Applied Anatomy.**—The veins of the rectal plexus are apt to become dilated and varicose, and form piles. This is due to several anatomical reasons: the vessels are contained in very loose connective tissue, so that they get less support from surrounding structures than most other veins, and are less capable of resisting increased blood-pressure; the condition is favoured by the fact that the superior rectal and portal veins have no valves; the veins pass through muscular tissue and are liable to be compressed by its contraction, especially during the act of defæcation; they are affected by every form of portal obstruction.

The **prostatic venous plexus** lies behind the inferior pubic ligament and the lower part of the symphysis pubis, and in front of the bladder and prostate (figs. 772 to 774). Its chief tributary is the deep dorsal vein of the penis, but it also receives tributaries from the front of the bladder and prostate. It communicates with the vesical plexus and with the internal pudendal vein, and drains into the vesical and internal iliac veins. The fibrous tissue in which the veins of the plexus are embedded constitutes the lateral part of the fascial sheath of the prostate.

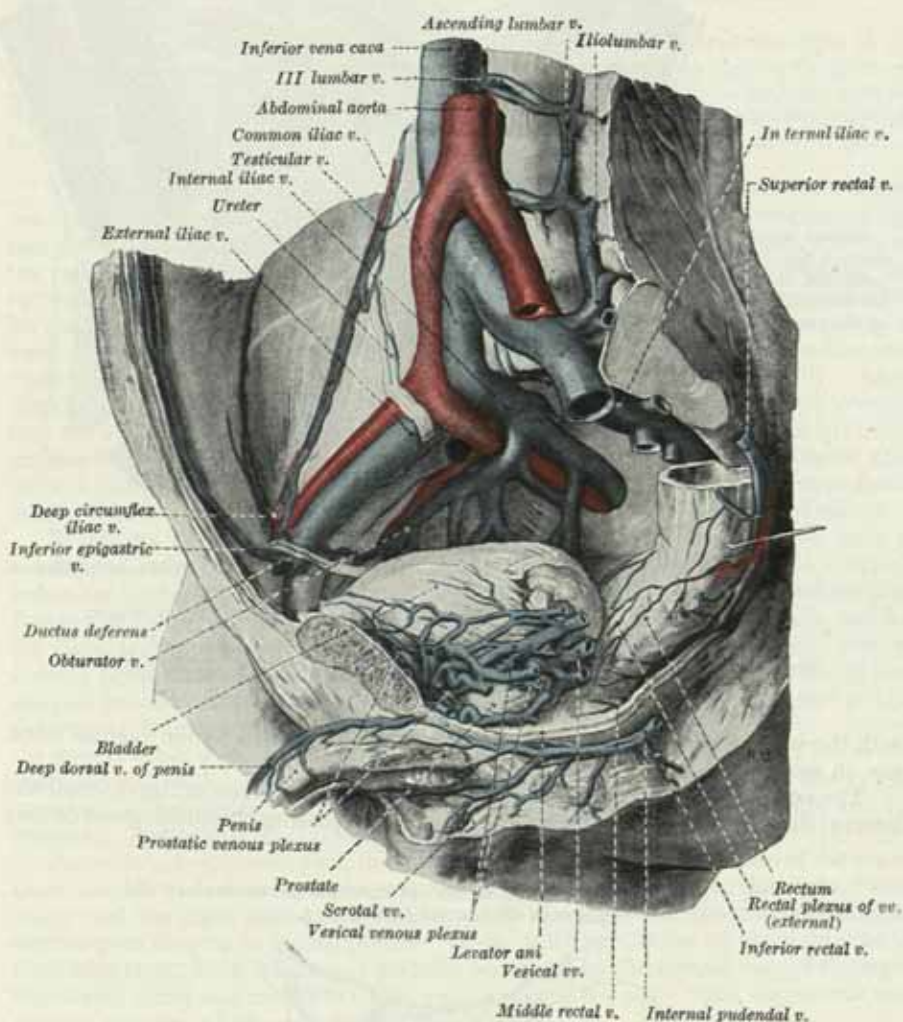
The **vesical plexus** envelops the lower part of the bladder and, in the male, the

* Consult also W. B. Gabriel, *Principles and Practice of Rectal Surgery*, H. K. Lewis, London, 1945.

base of the prostate. It communicates with the prostatic plexus in the male, and with the vaginal plexus in the female. It is drained, by means of several vesical veins which usually form a single trunk before entering the internal iliac vein.

The **dorsal veins of the penis** are two in number, a superficial and a deep : The *superficial dorsal vein* drains the prepuce and skin of the penis, and, running

FIG. 772.—The veins of the right half of the male pelvis. (Spalteholz.)



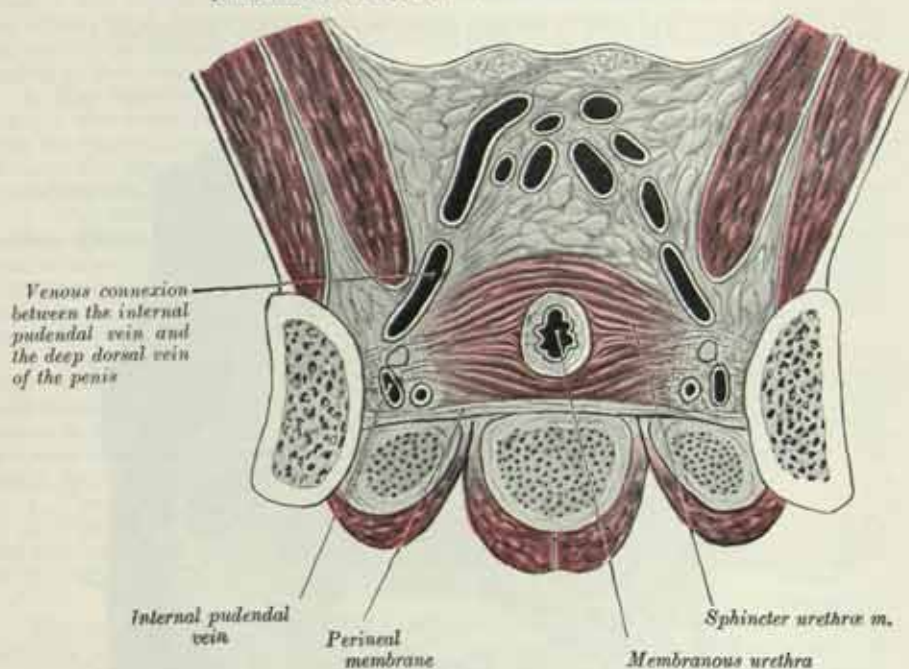
backwards in the subcutaneous tissue, inclines to the right or left, and opens into the corresponding external pudendal vein, a tributary of the great saphenous vein. The *deep dorsal vein* lies within the fibrous envelope of the penis ; it receives blood from the glans penis and corpora cavernosa penis, and courses backwards in the median plane between the dorsal arteries ; near the root of the penis it passes between the two parts of the suspensory ligament and then through an aperture between the inferior pubic ligament and the anterior margin of the perineal membrane, and divides into two branches, which enter the prostatic plexus after communicating below the symphysis pubis with the internal pudendal veins. The *dorsal vein of the clitoris*, after a similar course to that of the deep dorsal vein of the penis, ends in the vesical plexus.

The **uterine plexuses** lie along the sides and superior angles of the uterus between the two layers of the broad ligament, and communicate with the ovarian and vaginal plexuses. They are drained by a pair of uterine veins on each side ; these

arise from the lower parts of the plexuses, opposite the external os of the uterus, and open into the corresponding internal iliac vein.

The **vaginal plexuses** are placed at the sides of the vagina; they communicate

FIG. 773.—An oblique section of the pelvis and perineum made in the plane shown in Fig. 774. (After G. Elliot Smith.)

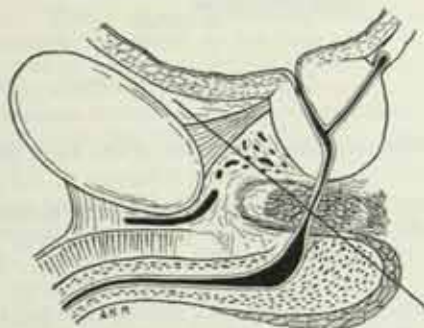


The pudendal nerve and the internal pudendal vessels are imbedded in fibro-areolar tissue which represents the forward continuation of the walls of the pudendal canal.

with the uterine, vesical and rectal plexuses, and are drained by the vaginal veins, one on each side, into the internal iliac veins.

The **common iliac veins** (fig. 772) are formed by the union of the external and internal iliac veins, in front of the sacro-iliac joint; passing obliquely upwards they

FIG. 774.—A median sagittal section of the male pelvis to show the plane of the section in Fig. 773.



end on the right side of the fifth lumbar vertebra by uniting with each other at an acute angle to form the inferior vena cava. The *right common iliac vein*, shorter than the left, is nearly vertical in its direction, and ascends behind, and then lateral to its artery. The right obturator nerve passes behind it obliquely, as it runs downwards and forwards to the obturator foramen. The *left common iliac vein*, longer and more

oblique than the right, is at first situated on the medial side of its artery, and then behind the right common iliac artery. It is crossed anteriorly by the root of the sigmoid mesocolon and the superior rectal vessels. In the rest of its course it is covered with peritoneum. Each common iliac vein receives the ilio-lumbar, and sometimes the lateral sacral veins; the left vein receives the median sacral vein. There are no valves in these veins.

The **median sacral veins** accompany the corresponding artery along the front of the sacrum, and join to form a single vein, which usually ends in the left common iliac vein, but sometimes in the angle of junction of the two common iliac veins.

Peculiarities.—The left common iliac vein, instead of joining with the right in its usual position, occasionally ascends on the left side of the aorta as high as the kidney, where, after receiving the left renal vein, it crosses the aorta, and joins the right vein to form the vena cava. In such cases the anomalous vessel represents the persistent caudal half of the posterior cardinal or of the supracardinal vein of the left side (p. 176).

The **inferior vena cava** (figs. 722, 772) conveys the blood from the parts below the Diaphragm to the right atrium of the heart. It is formed by the junction of the two common iliac veins, in front of the body of the fifth lumbar vertebra, a little to the right of the median plane. It ascends in front of the vertebral column, on the right side of the aorta, and, having reached the liver, is contained in a deep groove on its posterior surface—a groove which is occasionally converted into a tunnel by a band of liver substance. It then perforates the Diaphragm between the median and right portions of its tendinous centre, inclining slightly forwards and medially. After piercing the fibrous pericardium, it passes behind the serous pericardium to open into the lower and posterior part of the right atrium. In front and to the left of its atrial orifice there is a semilunar valve, termed the *valve of the inferior vena cava*; this valve is rudimentary in the adult, but is of large size and exercises an important function in the fœtus (p. 708). The trunk of the inferior vena cava is devoid of valves.

Relations of the abdominal portion.—*Anteriorly* the inferior vena cava is overlapped at its commencement by the right common iliac artery and is covered, below the horizontal part of the duodenum, with the posterior parietal peritoneum. It is crossed obliquely by the root of the mesentery and its contained vessels, and by the right testicular artery and, sometimes, transversely by the right colic artery. Passing behind the inferior part of the duodenum, it loses its peritoneal covering and ascends behind the head of the pancreas and then behind the superior part of the duodenum, from which it is separated by the bile duct and the portal vein. Above the duodenum it is again covered for a short distance with peritoneum and lies in the posterior wall of the epiploic foramen (aditus to the lesser sac) (figs. 1168 and 1170), by which it is separated from the right free border of the lesser omentum and its contents. Above this level it is covered by the liver.

Posteriorly, in its lower part, the inferior vena cava lies on the bodies of the lower three lumbar vertebrae and the anterior longitudinal ligament, the right Psoas major and the right sympathetic trunk, while the third and fourth right lumbar arteries pass deep to its medial border. In its upper part, it lies on the right crus of the Diaphragm, from which it is partially separated by the medial part of the right suprarenal gland and the right celiac ganglion, and the right renal, suprarenal and phrenic arteries, which cross behind it.

On its *right side* the inferior vena cava is related to the right ureter—with which, however, it is not in immediate contact—the descending part of the duodenum, the medial border of the right kidney and the right lobe of the liver.

On its *left side* it is related to the aorta, below, and to the right crus of the Diaphragm and the caudate lobe of the liver above.

Relations of the thoracic portion.—This part of the inferior vena cava is very short, and is situated partly inside and partly outside the pericardial sac. The *extra-pericardial part* is separated from the right pleura and lung by the right phrenic nerve. The *intra-pericardial part* is covered on the front and sides by the serous layer of the pericardium.

Surface Anatomy.—The vein begins on, or just below, the intertubercular plane and its centre lies 2.5 cm. from the median plane. 2.5 cm. wide, it ends above behind the sternal end of the sixth right costal cartilage. A line drawn from its lower end to a point 1 cm. medial to the mid-point between the anterior superior iliac spine and the

symphysis pubis indicates the course of the *common and external iliac veins* on each side. The line should have a slight convexity laterally, the curvature being greater on the left side.

Peculiarities.—Numerous anomalies of the inferior vena cava have been recorded and are attributable to arrests or errors in the complicated series of developmental changes which result in its formation. The vessel is sometimes represented, below the level of the renal veins, by two, more or less symmetrical veins. The condition is often associated with failure of the cross anastomosis connecting the two common iliac veins and is due to persistence on the left side of the body of one of the longitudinal channels (usually supra- or subcardinal) which normally disappear in early fetal life (p. 176). In complete transposition of the viscera, the inferior vena cava lies to the left side of the aorta.

Applied Anatomy.—Thrombosis of the inferior vena cava is much less common than thrombosis of the superior vena cava. It usually causes œdema of the legs and back, without ascites; if the renal veins are involved, blood and albumin will often appear in the urine. An extensive collateral venous circulation is soon established by enlargement either of the superficial or of the deep veins, or of both. In the first case the epigastric, the circumflex iliac, the lateral thoracic, thoraco-epigastric (p. 865), the internal thoracic, the posterior intercostals, the external pudendal and the lumbo-vertebral anastomotic veins effect the communication with the superior vena cava; in the second, the deep anastomosis is made by the azygos and hemiazygos and the lumbar veins.*

Tributaries.—In addition to the two common iliac veins the inferior vena receives the following veins:

Lumbar.	Renal.	Phrenic.
Right testicular or ovarian.	Right suprarenal.	Hepatic.

The **lumbar veins**, four in number on each side, collect the blood by dorsal tributaries from the muscles and skin of the loins, and by abdominal tributaries from the walls of the abdomen, where they communicate with the epigastric veins. At the vertebral column they receive veins from the vertebral plexuses, and they are connected with one another in this situation by the *ascending lumbar vein*—a longitudinal vessel placed in front of the roots of the transverse processes of the lumbar vertebrae. The *third and fourth lumbar veins* pass forwards on the sides of the bodies of the corresponding vertebrae and enter the posterior aspect of the inferior vena cava. Those of the left side pass behind the abdominal aorta and are longer than those of the right side. The *first and second lumbar veins* may end in the inferior vena cava or they may end in the ascending lumbar or lumbar azygos veins. As a rule, the first lumbar vein does not pass directly into the inferior vena cava. It may turn downwards to join the second and so open into it indirectly, but more frequently it ends in the ascending lumbar vein or passes forwards over the side of the body of the first lumbar vertebra and terminates in the lumbar azygos vein (p. 860). The second lumbar vein may join the inferior vena cava at or below the level of the renal veins. Sometimes it joins the third lumbar vein or it may terminate in the ascending lumbar vein. The first and second lumbar veins are frequently connected to each other, to the vessels of the opposite side, and to the right and left lumbar azygos veins by a plexiform network which lies on the bodies of the upper lumbar vertebrae.

The *ascending lumbar vein* is a longitudinal vessel which connects the common iliac, iliolumbar and lumbar veins. It is placed deeply under cover of the Psoas major and in front of the roots of the transverse processes of the lumbar vertebrae. At its upper end it joins the subcostal vein, and the trunk so formed turns forwards over the side of the body of the twelfth thoracic vertebra and, passing deep to the crus of the Diaphragm, ascends in the thorax as the azygos vein, on the right side, and as the inferior hemiazygos vein, on the left side. There is an angled bend on the vessel as it turns upwards, and it is usually joined at this point by a small vessel which springs from the back of the inferior vena cava (or from the left renal vein, on the left side). This little vessel represents the azygos line (p. 176), and has already been described as the *lumbar azygos vein*. Not infrequently the ascending lumbar vein ends in the first lumbar vein, which then turns forwards over the side of the first lumbar vertebra in company with the first lumbar artery and joins the lumbar azygos vein. In this case the subcostal vein joins the azygos vein (inferior hemiazygos vein, on the left side).

The **testicular veins** (fig. 722) emerge from the back of the testis, and receive tributaries from the epididymis; they unite and form a convoluted plexus, called

* G. Blumer, in Osler and McCrae's *System of Medicine*, London, 1908, vol. iv.

the *pampiniform plexus*, which constitutes the chief mass of the spermatic cord and ascends along the cord, in front of the ductus deferens. Below the superficial inguinal ring the veins of the plexus unite to form three or four veins, which pass along the inguinal canal, and, entering the abdomen through the deep inguinal ring, coalesce to form two veins, which run upwards in front of the Psoas major and the ureter, behind the peritoneum, lying one on each side of the testicular artery. These two veins join to form a single vessel, which on the right side opens into the inferior vena cava at an acute angle a little below the level of the renal veins; on the left side it opens into the left renal vein at a right angle. The testicular veins are provided with valves.* The left vein passes behind the lower part of the descending colon and the lower margin of the pancreas and is crossed by the left colic vessels; the right passes behind the terminal part of the ileum and the third part of the duodenum and is crossed by the root of the mesentery, the ileocolic and the right colic vessels.

Applied Anatomy. The testicular veins are very frequently varicose, constituting the condition known as *varicocele*. Varicocele almost invariably occurs on the left side, and this has been accounted for by the fact that the left testicular vein joins the left renal at a right angle; also it is overlaid by the lower part of the descending colon, and when this portion of the gut is full of faecal matter, in cases of constipation, its weight impedes the return of the venous blood.

After the removal of a varicocele the venous return is subsequently carried out by the small veins of the ductus deferens, of the Cremaster and those connecting with the scrotal tissues.

The **ovarian veins** in the female correspond with the testicular veins in the male; each forms a plexus between the layers of the broad ligament near the ovary and uterine tube, and communicates with the uterine plexus. Two veins issue from this plexus and ascend across the external iliac artery, one lying on each side of the ovarian artery. Their further course and their mode of termination are the same as those of the testicular veins. Valves are occasionally found in the ovarian veins. Like the uterine veins, they become much enlarged during pregnancy.

The **renal veins**, which are of large size, are placed in front of the renal arteries, and they open into the inferior vena cava almost at right angles. The *left* is thrice the length of the right (7.5 cm. to 2.5 cm.), and crosses the posterior abdominal wall, lying behind the splenic vein and the body of the pancreas. Near its termination it passes in front of the aorta, just below the origin of the superior mesenteric artery. The left testicular (or ovarian) vein enters it from below, and the left suprarenal vein, which generally receives one of the left phrenic veins, enters its upper border a little nearer the median plane. The left renal vein opens into the inferior vena cava at a slightly higher level than the right. The *right renal vein* lies behind the descending part of the duodenum and, sometimes, the lateral part of the posterior aspect of the head of the pancreas.

Occasionally the left renal vein may be duplicated, and in these cases one vein passes behind the aorta to join the inferior vena cava—persistence of the renal collar (p. 177)—or the anterior vessel may be entirely absent. The latter condition represents persistence of the posterior limb of the renal collar combined with absence of the intersubcardinal anastomosis.

The **suprarenal veins** are two in number, one issuing from the hilus of each suprarenal gland. The right vein is very short and passes directly into the posterior aspect of the inferior vena cava; the left runs downwards and medially, in front of or just lateral to the left celiac ganglion, and passes behind the body of the pancreas to end in the left renal vein.

The **phrenic veins** follow the course of the corresponding arteries on the Diaphragm; the right ends in the inferior vena cava; the left is often represented by two branches, one of which ends in the left renal or suprarenal vein, while the other passes in front of the oesophageal opening in the Diaphragm and joins the inferior vena cava.

The **hepatic veins** drain the liver, and commence in the *intralobular veins*, which receive the blood from the sinusoids of the liver lobules. The intralobular

* Rivington pointed out that valves are usually found at the orifices of both the right and left testicular veins. When, however, valves are not found at the opening of the left testicular vein into the left renal vein, they are generally present in the left renal vein within 6 mm. from the orifice of the testicular vein.—*Journal of Anatomy and Physiology*, vol. vii, p. 163.

veins open into the *sublobular veins*, and these in turn unite to form the hepatic veins, which open into the inferior vena cava as it lies in the groove on the posterior surface of the liver. The hepatic veins are arranged in two groups, upper and lower. The *upper group* usually consists of three large veins, right, left and middle, the last emerging from the caudate lobe; those of the *lower group* vary in number; they are of small size and come from the right and caudate lobes. The hepatic veins are in direct contact with the hepatic tissue and are destitute of valves.

THE PORTAL SYSTEM OF VEINS (fig. 775)

The portal system includes all the veins which drain the blood from the abdominal part of the digestive tube (with the exception of the lower part of the rectum and anal canal) and from the spleen, pancreas, and gall-bladder. From these viscera the blood is conveyed to the liver by the *portal vein*. In the liver this vein ramifies like an artery and ends in capillary-like vessels termed sinusoids, from which the blood is conveyed to the inferior vena cava by the hepatic veins. The blood of the portal system therefore passes through two sets of minute vessels, viz. (a) the capillaries of the digestive tube, spleen, pancreas, and gall-bladder; and (b) the sinusoids of the liver. In the adult the portal vein and its tributaries are destitute of valves; in the fœtus and for a short time after birth valves can be demonstrated in the tributaries of the portal vein; as a rule they atrophy and disappear, but sometimes they persist in a degenerate form.

The **portal vein** (figs. 775, 776) is about 8 cm. long, and is formed at the level of the second lumbar vertebra by the junction of the superior mesenteric and splenic veins, the union of these veins taking place in front of the inferior vena cava and behind the neck of the pancreas. It may be separated from the inferior vena cava by the upper part of the head of the pancreas, when that structure projects to the left. The vein inclines to the right as it passes upwards behind the superior part of the duodenum, the bile-duct and the gastroduodenal artery, and in front of the inferior vena cava; it then ascends in the right border of the lesser omentum in front of the epiploic foramen (aditus to the lesser sac) to reach the right extremity of the porta hepatis, where it divides into right and left branches, which accompany the corresponding branches of the hepatic artery into the substance of the liver. In the lesser omentum it is placed behind the bile duct and the hepatic artery, the former lying to the right of the latter; it is surrounded by the hepatic plexus of nerves, and is accompanied by numerous lymph vessels and some lymphatic nodes. The *right branch* of the portal vein enters the right lobe of the liver, but before doing so generally receives the cystic vein. The *left branch*, longer but of smaller calibre than the right, gives branches to the caudate and quadrate lobes and then enters the left lobe of the liver. As it does so, it is joined in front by the para-umbilical veins (p. 876) and by a fibrous cord, named the *ligamentum teres*, which represents the obliterated umbilical vein. It is connected to the inferior vena cava by a second fibrous cord, termed the *ligamentum venosum*, which ascends in a fissure on the posterior aspect of the liver.

The tributaries of the portal vein are:

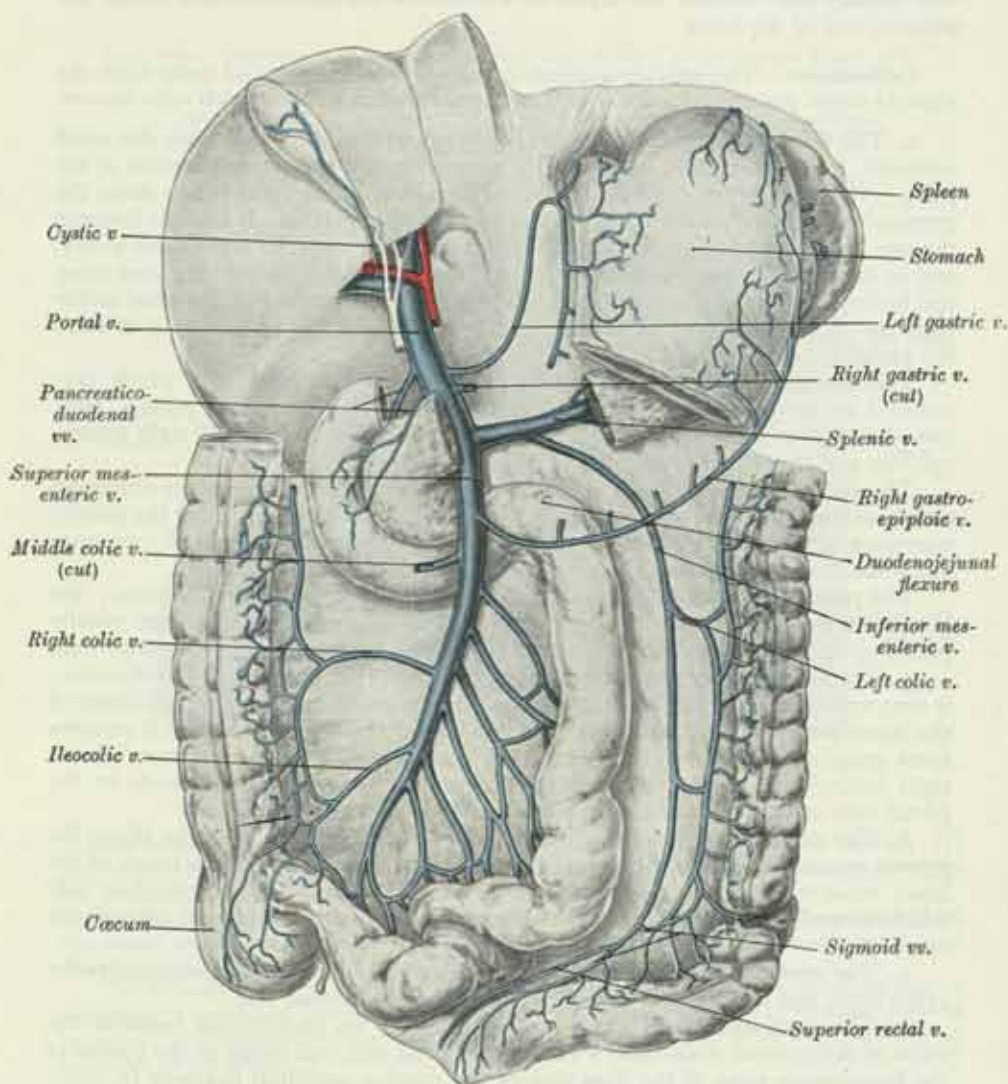
- | | |
|-------------------------|--------------------|
| 1. Splenic. | 4. Right gastric. |
| 2. Superior mesenteric. | 5. Cystic. |
| 3. Left gastric. | 6. Para-umbilical. |

1. The **splenic vein** (fig. 775) is of large size, but is not tortuous like the artery; it commences by five or six branches which return the blood from the spleen. These unite to form a single vessel, which traverses the lienorenal ligament in company with the splenic artery and the tail of the pancreas. It then passes to the right with a downward inclination across the posterior abdominal wall, lying at a lower level than the splenic artery and grooving the upper part of the posterior surface of the pancreas, to which it is closely connected by numerous short tributaries from the gland. In its course it crosses the anterior surface of the left kidney and its hilus (or the lower pole of the left suprarenal gland), and it is separated from the left sympathetic trunk and crus of the Diaphragm by the left renal vessels, and from the abdominal aorta by the superior mesenteric artery and the left renal vein. It ends behind the neck of the pancreas where it unites at a right angle with the superior mesenteric vein, to form the portal vein.

Tributaries.—It receives the short gastric veins, the left gastro-epiploic vein, the pancreatic veins, and the inferior mesenteric vein.

(a) The **short gastric veins**, four or five in number, drain the fundus and left part of the greater curvature of the stomach, and pass between the two layers of the gastrosplenic ligament to end in the splenic vein or in one of its large tributaries.

FIG. 775.—The portal vein and its tributaries. Semi-diagrammatic.



Portions of the stomach, pancreas and left lobe of the liver, and the transverse colon have been removed.

(b) The **left gastro-epiploic vein** receives branches from both surfaces of the stomach and from the greater omentum; it runs from right to left along the greater curvature of the stomach and ends in the commencement of the splenic vein.

(c) The **pancreatic veins** are several small vessels which drain the body and tail of the pancreas.

(d) The **inferior mesenteric vein** (fig. 775) returns blood from the rectum, and from the sigmoid and descending parts of the colon. It begins in the rectum as the **superior rectal vein**, which has its origin in the rectal plexus (p. 868), and through this plexus communicates with the middle and inferior rectal veins. The superior rectal vein leaves the lesser pelvis, crosses the left common iliac vessels with the superior rectal artery, and is continued upwards as the inferior mesenteric vein.

This vein lies to the left of its artery and ascends behind the peritoneum and in front of the left Psoas major; its course is usually curved, convex to the left, and it may cross the testicular (or ovarian) vessels or lie to their medial side; it then passes above, or behind, the duodenojejunal flexure and opens into the splenic vein behind the body of the pancreas; sometimes it ends in the angle of union of the splenic and superior mesenteric veins.

If a superior duodenal or a paraduodenal fossa be present, the inferior mesenteric vein usually lies between the layers of the fold of peritoneum which forms the anterior wall of the fossa.

Tributaries.—The inferior mesenteric vein receives the sigmoid veins from the sigmoid colon, and the left colic vein from the descending colon and left colic flexure.

2. The **superior mesenteric vein** (fig. 775) returns the blood from the small intestine, from the cæcum, and from the ascending and transverse portions of the colon. It begins in the right iliac fossa by the union of the veins which drain the terminal part of the ileum, the cæcum and vermiform appendix. It ascends between the two layers of the mesentery on the right side of the superior mesenteric artery, and in its upward course passes in front of the right ureter, the inferior vena cava, the horizontal part of the duodenum, and the uncinat process of the head of the pancreas. Behind the neck of the pancreas it unites with the splenic vein to form the portal vein.

Tributaries.—The superior mesenteric vein receives the veins which correspond to the branches of the superior mesenteric artery, viz. the jejunal, ileal, ileocolic, right colic, and middle colic veins; it is also joined by the right gastro-epiploic and the pancreaticoduodenal veins.

The **right gastro-epiploic vein** receives branches from the greater omentum and from the lower part of the stomach; it runs from left to right along the greater curvature of the stomach, between the anterior two layers of the greater omentum and joins the superior mesenteric vein below the neck of the pancreas.

The **pancreaticoduodenal veins** accompany their corresponding arteries; the lower one frequently joins the right gastro-epiploic vein; the upper one usually passes upwards and to the left behind the bile duct and terminates in the portal vein.

3. The **left gastric vein** derives tributaries from both surfaces of the stomach; it runs upwards along the lesser curvature of the stomach between the two layers of the lesser omentum, to the œsophageal opening of the stomach, where it receives some œsophageal veins. It then turns backwards and passes downwards and to the right behind the omental bursa (lesser sac of the peritoneum), and ends in the portal vein at the upper border of the superior part of the duodenum.

4. The **right gastric vein**, of small size, runs from left to right along the pyloric portion of the lesser curvature of the stomach between the two layers of the lesser omentum, and ends in the portal vein. It is joined by the *prepyloric vein* which ascends in front of the pylorus and usually marks the site of the pyloric opening.

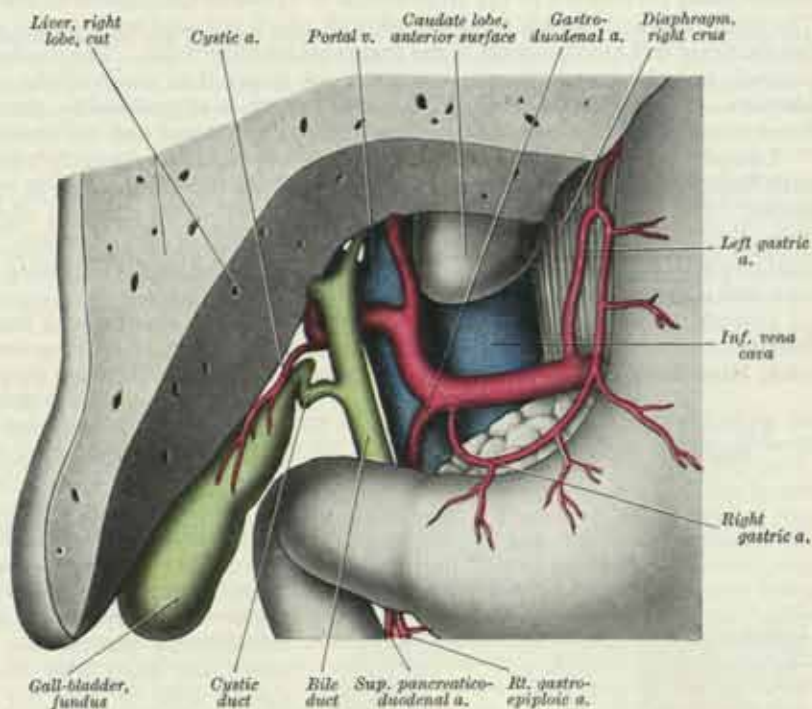
5. The **cystic vein** drains the blood from the gall-bladder; it accompanies the cystic duct, and usually ends in the right branch of the portal vein.

6. The **para-umbilical veins**, which establish an anastomosis between the veins of the anterior abdominal wall and the portal vein, are found in the course of the ligamentum teres of the liver and of the median umbilical ligament (p. 877). The best marked of these small veins is one which begins at the umbilicus and runs backwards and upwards in, or on the surface of, the ligamentum teres between the layers of the falciform ligament, to end in the left branch of the portal vein.

Applied Anatomy.—Obstruction to the portal vein may produce ascites, whether the site of the obstruction is (1) intra- or (2) extra-hepatic. (1a). In cirrhosis of the liver, the radicles of the portal vein are compressed by the contraction of the fibrous tissue in the portal canals. (1b). In valvular disease of the heart backward pressure on the hepatic veins and so on the whole circulation through the liver must have a similar effect. In addition the portal vein may be compressed by tumours of the liver, such as cancer or hydatid cyst, or by enlarged lymph nodes in the lesser omentum or cancer of the head of the pancreas. In the latter the obstruction is extra-hepatic. In these conditions the prognosis as regards life and freedom from ascites may be much improved by the establishment of a good collateral circulation between the portal and systemic veins. This is effected by communications between (a) the

gastric veins, and the œsophageal veins which often project as a varicose bunch into the stomach, emptying themselves into the inferior hemiazygos vein; (b) the veins of the colon and duodenum, and the left renal vein; (c) the accessory portal system of Sappey, branches of which pass in the round and falciform ligaments (particularly the latter) to unite with the epigastric and internal thoracic veins, and through the diaphragmatic veins with the azygos; a single large vein, termed a para-umbilical vein, may pass from the hilus of the liver by the round ligament to the umbilicus, producing there a bunch of prominent varicose veins known as the *caput Medusæ*; (d) the veins of Retzius, which connect the intestinal veins with the inferior vena cava

FIG. 776.—Drawing of a dissection to show the relations of the hepatic artery, bile duct and portal vein in the lesser omentum.



and its retroperitoneal branches; (e) the superior, middle and inferior rectal; (f) very rarely the ductus venosus remains patent, affording a direct connexion between the portal vein and the inferior vena cava.

Some success has been achieved in cases of portal obstruction by anastomosis of the portal vein to the inferior vena cava or of the splenic vein to the left renal vein after removal of the spleen.*

Thrombosis of the portal vein is a very serious event, and is most often due to pathological processes causing compression of the vessel or injury to its wall, such as tumours or inflammation about the pylorus or head of the pancreas, or to gall-stones, or cirrhosis of the liver.

THE LYMPHATIC SYSTEM †

In most of the tissues of the body there exists a wide-meshed plexus of vessels which contain a clear, colourless fluid. This fluid is termed *lymph* and it is composed, for the most part, of blood plasma which has transuded through the walls of the blood capillaries into the minute tissue spaces and has there become mixed with the tissue juices. As the pressure in these tissue spaces rises, the fluid which they contain passes into a closed system of vessels, termed *lymph vessels*. These eventu-

* Alfred Blalock, Churchill Lecture, *Annals of Surgery*, 125, No. 2, p. 129.

† For a full account of the recent work on the lymphatic system the reader is referred to "Lymphatics, Lymph and Lymphoid Tissue," C. K. Drinker and J. M. Yoffey, *Harvard University Monograph in Medicine and Public Health* No. 2, and J. M. Yoffey and F. C. Courtice. Second edition, 1956. Publ. by Edward Arnold (Publishers) Ltd., London.

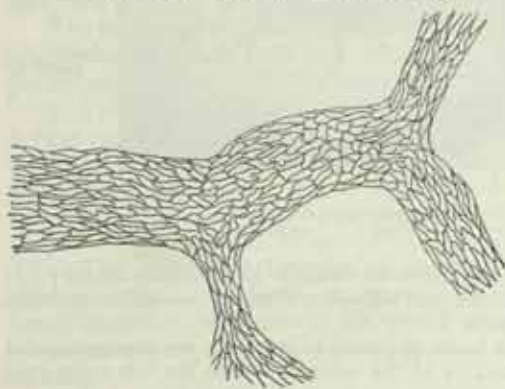
ally discharge the lymph into the great veins at the root of the neck, but all, save the terminal vessels, are interrupted in some part of their course by small, solid masses of lymphoid tissue, termed *lymph nodes (glands)*. The lymphatic system comprises not only all the lymph vessels and lymph nodes which will be described in this section, but also certain masses of lymphoid tissue found mainly in the walls of the alimentary canal which will be described with the digestive system.

The **lymph vessels** are exceedingly delicate and their coats so transparent that the fluid they contain is readily seen through them. In contrast with the blood-capillaries, which can absorb only those substances which are soluble in water, the lymph vessels are able to take up substances which are insoluble in water.* They are constricted at intervals and so present a knotted or beaded appearance; these constrictions correspond to the attachments of valves in the interior of the vessels. The smallest lymph vessels form a meshwork which is found interspersed amongst the elements and blood-vessels of the tissues which they drain. The meshes of the network and the vessels themselves are much larger than those of the capillary plexuses. The walls of the vessels are complete and, in all probability, there are no direct communications between the lumen of a lymph vessel and the tissue spaces.

Lymph vessels have been found in nearly every tissue of the body which contains blood-vessels, but it would appear that they are more numerous in epithelial tissues. The lymph vessels of the small intestine are called *lacteals*; they differ from other lymph vessels only in regard to their function of fat absorption. After a meal containing this foodstuff, the lymph which they contain is milk-white in appearance and is termed *chyle*.

Lymph vessels are absent from the central nervous system, and from non-vascular structures such as cartilage, nails, cuticle and hair. Their occurrence in bone, bone-marrow, and in striped muscle, is doubtful. In the lung they do not

FIG. 777.—A small lymph vessel, from the diaphragm of a rabbit. Silvered. $\times 65$.



reach the pulmonary alveoli but cease at the beginnings of the atria; nor are they found in the interior of the liver lobules or in the splenic pulp. Although no lymph vessels are found in the central nervous system, the blood-vessels entering the brain and spinal cord appear to be surrounded by perivascular spaces which are lined with the mesothelial cells of the pia mater. The cerebrospinal fluid circulates through these spaces and may therefore play the part of lymph. Woollard,† who used the vital method of injecting the subarachnoid space in cats, found that subsequently the dye was confined

to the pia and arachnoid mater, and that these structures, together with the pial septa, were everywhere coloured. Further, the mesothelial cells of the pia mater contained granules of the dye and it could be traced for considerable distances along the spaces in the sheaths of the blood-vessels entering the brain and spinal cord. These perivascular spaces may therefore be regarded as playing the part of lymph vessels.

From the networks in the tissues small lymph vessels emerge and either pass to a neighbouring lymph node or join some larger lymph trunk. The vessels are arranged in superficial and deep sets. The *superficial lymph vessels* lie immediately under the skin and may run independently or may accompany the superficial veins; in certain situations they join the deep vessels, but these connexions are by no means frequent. The superficial lymph vessels are especially numerous around the orifices where skin and mucous membrane become continuous, e.g., the mouth, the anus, the vagina, etc. Lymph vessels of a similar type are found in the submucous areolar

* P. T. Herring and F. G. Macnaughton, *The Lancet*, June 3rd, 1922.

† H. H. Woollard, *J. Anat.*, 58, 1922.

tissue of the digestive, respiratory and urogenital systems and in the subserous tissue of the thoracic and abdominal walls. The *deep lymph vessels* always accompany vascular or neurovascular bundles; they are fewer in number but larger in calibre than the superficial vessels, although their mode of origin is probably similar.

The lymph vessels of any part exceed the veins in number, but they are much smaller in size. Their anastomoses—especially those of the larger trunks—are more numerous and are effected by vessels equal in diameter to those which they connect.

The lymph vessels unite with one another and ultimately form two main channels, named the *thoracic duct* and the *right lymphatic duct*, which open into the venous system at the root of the neck.

The structure of the lymph vessels.—The walls of the larger lymph vessels are composed of three coats. The *internal* coat is thin, transparent, and slightly elastic, and consists of a layer of elongated endothelial cells supported on an elastic membrane; the cells have wavy margins, by which contiguous cells are dovetailed into one another. The *middle* coat is composed of smooth muscular, and fine elastic fibres, disposed in a transverse direction. The *external* coat consists of connective tissue, intermixed with smooth muscular fibres—longitudinally or obliquely disposed; it forms a protective covering to the other coats and serves to connect the vessel with the neighbouring structures. In the smaller vessels there are no muscular or elastic fibres, and the wall consists only of a connective tissue coat lined by endothelium (fig. 777). The thoracic duct has a more complex structure than the other lymph vessels; it presents a distinct subendothelial layer, similar to that found in the arteries; in the middle coat there is, in addition to the muscular and elastic fibres, a layer of connective tissue with its fibres arranged longitudinally. Nutrient blood-vessels and many non-medullated nerves in the form of fine plexuses are distributed to the outer and middle coats of the larger lymph-vessels.

In the lymph vessels the valves are placed at much shorter intervals than in the veins. They are most numerous near the lymph nodes, and are found more frequently in the lymph vessels of the neck and upper limb than in those of the lower limb; they are wanting in the vessels composing the plexiform network in which the lymph vessels usually originate on the surface of the body. The valves are formed of thin layers of fibrous tissue covered on both surfaces by endothelium which presents the same arrangement as on the valves of veins (p. 692). They are semilunar in form, and are attached by their convex edges to the wall of the vessel, the concave edges being free and directed along the course of the lymph-current. Usually two valves, of equal size, are found opposite each other; but occasionally exceptions occur, especially at or near the anastomoses of lymph vessels; thus, one valve may be of small size and the other increased in proportion. The wall of a lymph vessel immediately above the attachment of each segment of a valve is expanded into a pouch or sinus which gives the vessel, when distended, the knotted or beaded appearance to which reference has already been made.

The **lymph nodes** are small, oval or bean-shaped bodies, situated in the course of lymph and lacteal vessels so that the lymph and chyle pass through them on their way to the blood. Generally each presents on one side a slight depression, termed the *hilus*, through which the blood-vessels enter and leave the node. The efferent lymph vessel also emerges from the node at this spot, while the afferent vessels enter it at different parts of the periphery. On section, a lymph node displays two different structures: an external, of lighter colour—the *cortical*; and an internal, darker—the *medullary*. The cortical structure does not form a complete investment but is deficient at the hilus, where the medullary portion reaches the surface of the node; so that the efferent lymph vessel is derived directly from the medullary structure, while the afferent vessels empty themselves into the cortical substance.

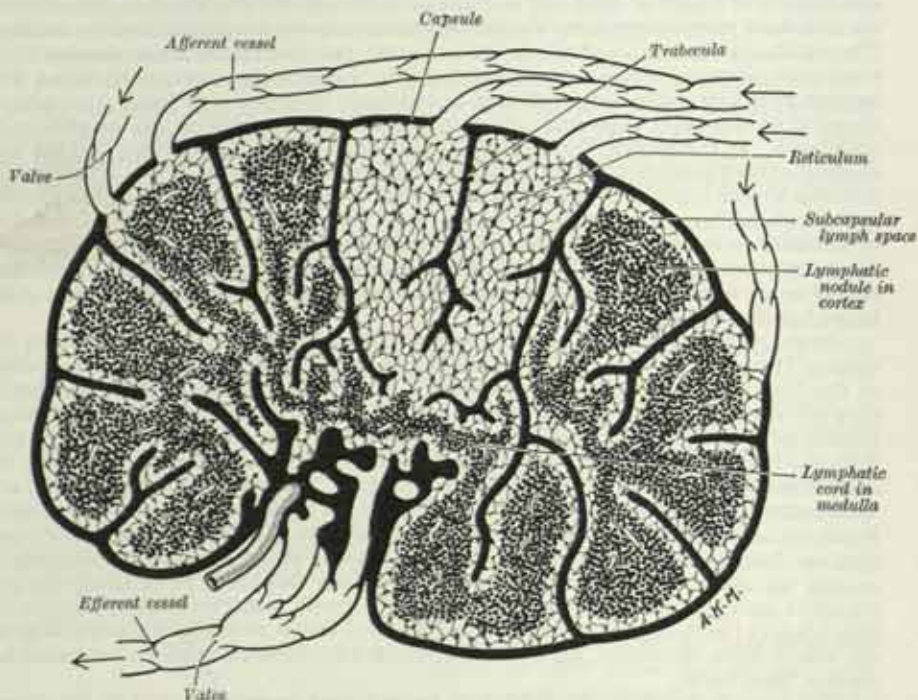
The structure of the lymph nodes (figs. 778, 779).—A lymph node consists of a framework comprising the capsule, trabeculae and the reticular tissue and, entangled in this framework, masses of lymphocytes and free macrophages.

The capsule and trabeculae.—The capsule, which is composed mainly of collagen fibres with a few fibroblasts between the bundles, contains also some elastic fibres, especially in its deeper layers. In some animals a great many plain muscle fibres are found but this is not the case in man. The capsule covers the outside of the node and is continuous, on its deep surface, with trabeculae of a similar structure which extend into the interior of the node for about one-fourth to one-third of the distance from the periphery to the centre. At the hilus, dense fibrous tissue may extend some distance into the medulla and the efferent vessel is embedded in this before it leaves the node. The majority of the blood-vessels enter and leave at the hilus and their main branches

follow the trabeculae to reach their distribution to a capillary plexus in the substance of the node tissue.

The reticulum.—The reticulum forms a meshwork everywhere within the spaces outlined by the capsule and trabeculae. In some parts, for example in the cortex, it can be seen only with difficulty because of the large number of lymphocytes entangled in its mesh. In other parts it is easily seen because fewer cells are entangled and the mesh of the reticulum itself is looser; such parts allow the lymph to pass through with little hindrance and are termed the *lymph sinuses*. Entangled cells are almost entirely absent from the portion immediately beneath the capsule where the reticular mesh is readily seen in the lymph sinus called the *subcapsular lymph space*. The latter is continuous with similar spaces alongside the trabeculae which carry the lymph into the medulla where the reticulum is again fairly easy to see because of the small number of entangled cells.

FIG. 778.—A scheme of a lymph node. (Modified from Maximov and Bloom.)



Note.—In two of the lobules, the lymphocytes have been omitted to show the reticulum.

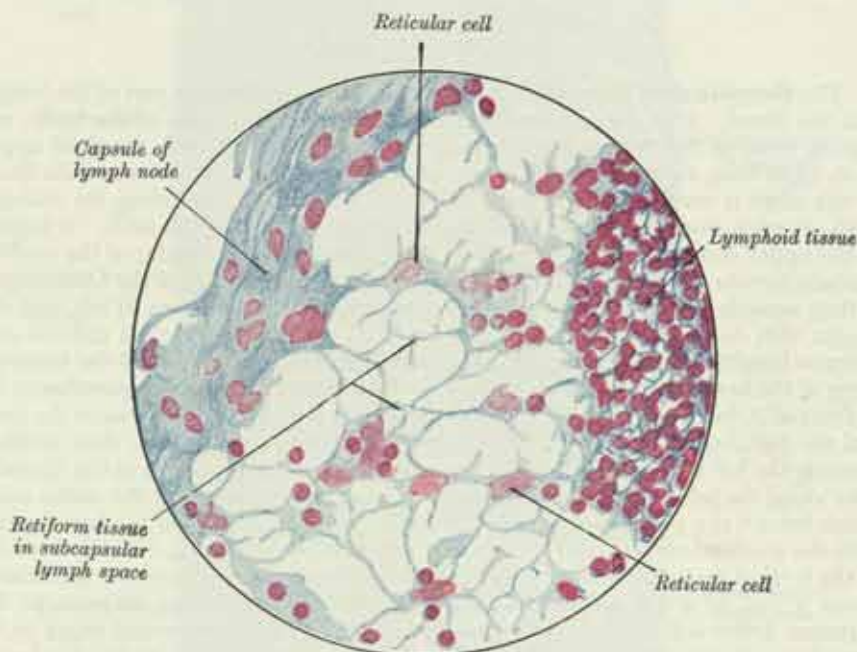
The reticulum itself consists of reticular fibres and reticular cells. The *reticular fibres* are extremely fine collagen fibres produced by the primitive reticular cells. They are numerous and form a close meshwork at the periphery of the cortical lymph nodules and round the blood-vessels, whilst, in the lymph sinuses and at the centres of the lymphatic nodules, the mesh is much looser. The *reticular cells* are of two types, viz. the primitive reticular cells and the phagocytic reticular cells or fixed macrophages. The primitive reticular cells form a syncytium in close association with the reticular fibres which have been produced by the cells. Some of the macrophages which line the lymph sinuses are quite prominent and are capable of active phagocytosis. They can pick up from the lymph particulate matter or bacteria which might otherwise reach the blood-stream. Other macrophages are flattened like endothelial cells, but, if a demand is made on them, they can become more prominent and exhibit the capacity for phagocytosis.

The entangled cells.—The majority of the cells entangled in the reticulum are *lymphocytes*, although *macrophages* which have become freed from the reticulum are often found in the lymph sinuses. The distribution of the lymphocytes is different in the various parts of the node. In the lymph sinuses are found some free cells which have been swept into the lymph as it circulates through the node. In the cortical part the cells are very densely packed and may form more or less isolated masses called *lymph nodules* or *lymph follicles*. The number and the degree of isolation of the nodules

vary from time to time according to the demands made by the body on lymphoid tissue generally. The central part of each nodule is composed of cells which are larger, less deeply staining and dividing more rapidly, than those at the periphery. These central areas are called *germinal centres*. In the medullary part of the node the lymphocytes are much more loosely packed than they are in the cortex. They constitute irregular branching cords between which the reticulum of the medullary lymph sinuses is easily seen.

The *afferent vessels*, as stated above, enter at different parts of the periphery of the gland, and after branching and forming a dense plexus in the substance of the capsule, open into the part of the lymph sinus immediately beneath the capsule. This *subcapsular lymph space* is everywhere in continuity with the lymph sinuses of the cortical part. As the afferent vessels enter they lose all their coats except their endothelial lining, which is continuous with the layer of cells lining the lymph sinuses. The *efferent vessel* commences from the lymph sinuses of the medullary

FIG. 779.—Retiform and adenoid tissue, from a lymph node. $\times 255$.



portion. The stream of lymph carried to the gland by the afferent vessels thus passes through the plexus in the capsule to the lymph sinuses of the cortical portion, where it is exposed to the action of the node pulp; after flowing through these it enters the sinuses of the medullary portion, and finally emerges from the hilus by means of the efferent vessel. The stream of lymph in its passage through the lymph sinuses is retarded slightly by the presence of the reticulum, hence morphological elements carried in the lymph stream, either normal or morbid, are easily arrested and deposited in the sinuses. Many lymph corpuscles pass with the efferent lymph-stream to join the general blood-stream.

Applied Anatomy.—The lymph vessels and lymph nodes draining any infected area of the body are very liable to become inflamed, resulting in acute or chronic lymphangitis and lymphadenitis. In acute cases the paths of the superficial lymph vessels are often marked out on the skin by painful, red lines leading to tender, swollen lymph nodes, which may suppurate. Chronic lymphangitis, together with the blocking of numerous lymphatic vessels by the escaped ova of the minute parasitic worm *Microfilaria nocturna*, is the cause of elephantiasis, a condition common in the tropics and subtropics, and characterised by enormous enlargement and thickening of the skin of some part of the body, most frequently of the leg and scrotum. Tuberculous, syphilitic and cancerous enlargements of the lymph vessels and lymph nodes are very commonly met with.

The present view is that cancer spreads both by minute emboli and by permeating the lymph vessels as a solid cell-growth. Operations for the removal of cancer are therefore planned to take away in one mass the cancer, the intervening lymph vessels, and the lymph nodes.

The appearance of secondary malignant deposits or of secondary infection in parts of the body that seem not to be directly associated by any lymphatic connexion with the seat of the primary growth or infection has often been observed, and explained as due to 'retrograde transport' of cancer-cells or bacteria by a reversed flow of lymph. Weleminsky,* however, believes that the explanation is to be found in the fact that when the infected lymph nodes have grown to a certain size they no longer permit the normal flow of lymph through them, and that in these circumstances very delicate lymphatic connexions, whose existence normally remains unsuspected, develop to a surprising extent between groups of lymph glands that at first sight appear to be unconnected with one another. In this connexion the possibility of spread by the blood-stream should not be disregarded entirely. It has been shown† that lymph vessels in a pedicle skin graft survive in the graft and can replace vessels which have been destroyed.

THE THORACIC DUCT

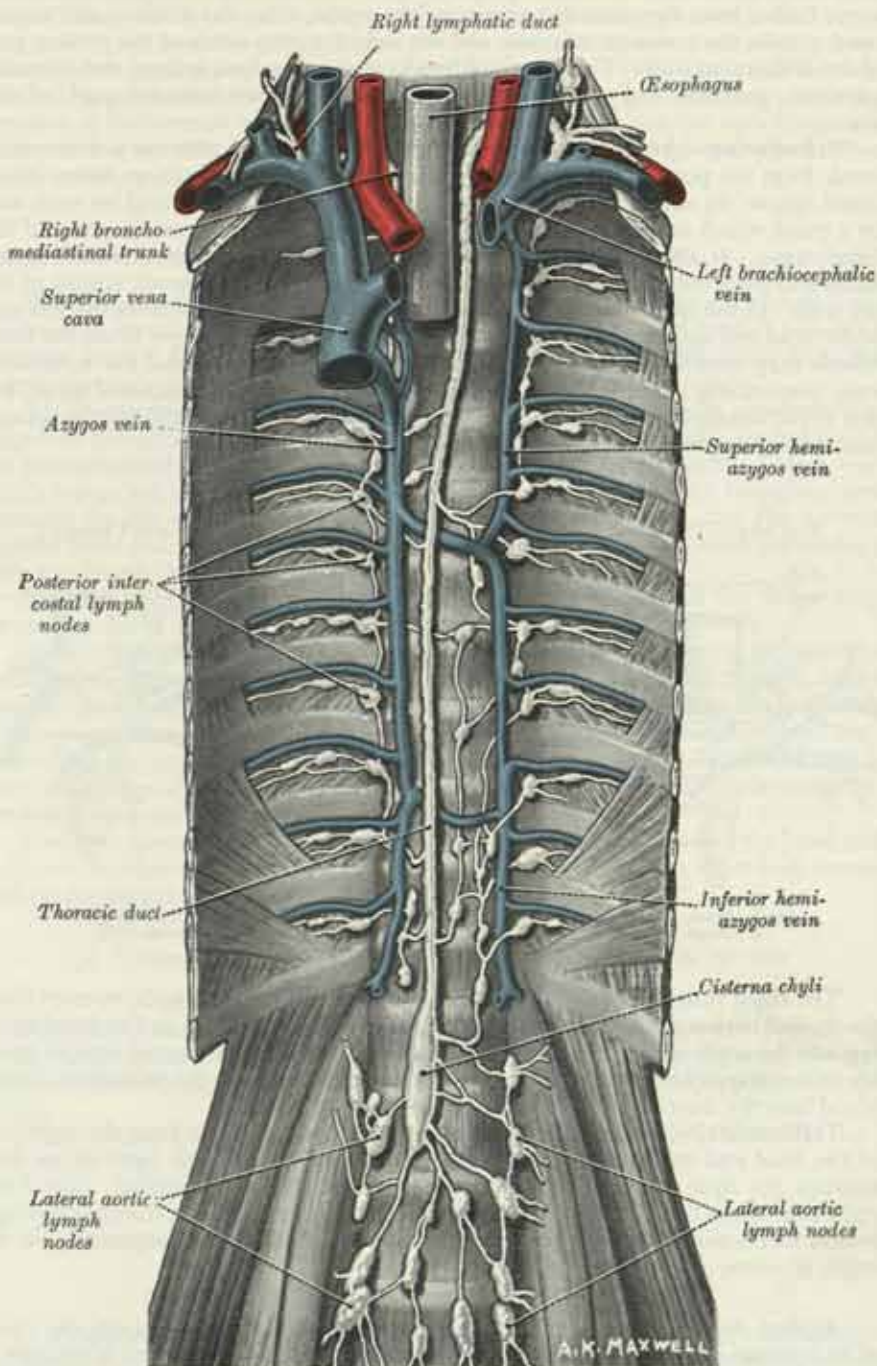
The **thoracic duct** (fig. 780) conveys the chyle and the greater part of the lymph into the blood. It is the common trunk of all the lymph vessels of the body, excepting those of the right side of the head, neck, and thoracic wall, the right upper limb, right lung, right side of the heart, and part of the convex surface of the liver. In the adult it varies in length from 38 cm. to 45 cm. and, including the cisterna chyli, extends from the second lumbar vertebra to the root of the neck. It begins at the upper end of the cisterna chyli (p. 883) near the lower border of the twelfth thoracic vertebra and enters the thorax through the aortic opening of the Diaphragm. It then ascends through the posterior mediastinum with the aorta on its left, and the azygos vein on its right side. In this part of its course the vertebral column and anterior longitudinal ligament, the right aortic intercostal arteries, and the terminal parts of the hemiazygos veins lie behind it. The Diaphragm and the œsophagus lie in front of it, but a recess of the right pleural cavity may intervene between the duct and the œsophagus. Opposite the fifth thoracic vertebra the thoracic duct inclines towards the left side, enters the superior mediastinum, and ascends to the thoracic inlet along the left edge of the œsophagus. After being crossed by the aortic arch, it lies behind the commencement of the left subclavian artery and in close contact with the mediastinal pleura of the left side. Passing into the neck, it arches laterally at the level of the transverse process of the seventh cervical vertebra, the arch rising about 3 cm. or 4 cm. above the clavicle. Here the duct runs anterior to the vertebral artery and vein, the sympathetic trunk and the thyrocervical trunk or its branches. It also passes in front of the phrenic nerve and the medial border of the Scalenus anterior, but is separated from these two structures by the prevertebral fascia. In this situation it is placed behind the left common carotid artery, vagus nerve, and internal jugular vein. Finally, it descends in front of the first part of the left subclavian artery and ends by opening into the angle of junction of the left subclavian vein with the left internal jugular vein. Sometimes it breaks up into a variable number of smaller vessels just prior to its termination. At its commencement the thoracic duct is about .5 cm. in diameter, but it diminishes considerably in calibre in the middle of the thorax, and is again slightly dilated just before its termination. It is generally flexuous, and constricted at intervals so as to present a varicose appearance. Not infrequently it divides in the middle of its course into two vessels of unequal size which soon reunite, or into several branches which form a plexiform interlacement. It occasionally divides at its upper part into two branches, right and left; the left ending in the usual manner, while the right opens into the right subclavian vein, in connexion with the right lymphatic duct. The thoracic duct has several valves, and these tend to be placed in situations where the duct is exposed to pressure; at its termination it is provided with a pair, the free borders of which are turned towards the vein so as to prevent the passage of venous blood into the duct.

* *Berliner klin. Woch.*, 1905, No. 24, p. 743.

† J. H. Gray, *J. Anat.*, 72, 1937.

The **cisterna chyli** (fig. 78o) is a sac-like dilatation on the lymphatic pathway from the abdomen and lower limbs. It is 5 cm. to 7 cm. long and is situated in front

FIG. 78o.—The thoracic and right lymphatic ducts.



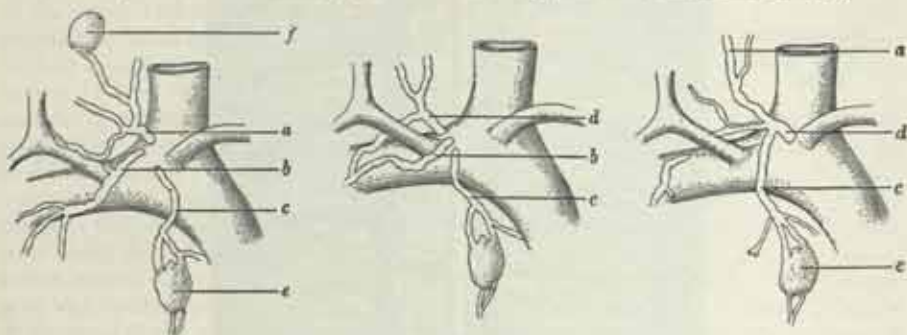
Note.—The inferior hemiazygos vein is crossing the median plane at a lower level than usual while the superior hemiazygos is crossing at a higher level than usual.

of the bodies of the first and second lumbar vertebræ, immediately to the right of the abdominal aorta. The upper two lumbar arteries of the right side and the right

lumbar azygos vein, when it is present, intervene between the cisterna chyli and the vertebral column. Anteriorly the cisterna chyli is covered by the medial edge of the right crus of the Diaphragm. It receives the right and left lumbar and the intestinal lymphatic trunks. The *lumbar trunks* are formed by the union of the efferent vessels from the lumbar (lateral aortic) lymph nodes; they receive the lymph from the lower limbs, from the walls and viscera of the pelvis, from the kidneys and suprarenal glands, the testes (or ovaries), and the deep lymph vessels of the greater part of the abdominal wall. The *intestinal trunk* receives the lymph from the stomach, intestine, pancreas and spleen, and from the lower and anterior part of the liver.

Tributaries.—At its commencement the thoracic duct receives a descending trunk from the posterior intercostal lymph node of the lower six or seven intercostal spaces, on each side. In the thorax the thoracic duct is joined on each side by a trunk which drains the upper lumbar lymph nodes and pierces the crus of the Diaphragm. It also receives the efferents from the posterior mediastinal lymph nodes and from the posterior intercostal lymph nodes of the upper six spaces of the left side. In the neck it is joined usually by the *left jugular trunk* from the left side of the head and neck, and the *left subclavian trunk* from the left upper limb, but these vessels may open independently into the internal jugular vein and the subclavian vein, respectively; sometimes it is joined by the *left bronchomediastinal trunk*, but this trunk usually opens independently into the junction of the left subclavian and internal jugular veins.

FIG. 781.—The terminal lymph trunks of the right side. (Poirier and Charpy.)



a, Jugular trunk. b, Subclavian trunk. c, Bronchomediastinal trunk. d, Right lymphatic duct. e, Lymph node of internal thoracic chain. f, Lymph node of deep cervical chain.

The **right lymphatic duct** (figs. 780, 781), about 1 cm. in length, courses along the medial border of the *Scalenus anterior* at the root of the neck, and ends by opening into the angle of junction of the right subclavian and right internal jugular veins. Its orifice is guarded by two semilunar valves, which prevent the passage of venous blood into the duct.

Tributaries.—The right lymphatic duct receives the lymph from the right side of the head and neck through the *right jugular trunk*; from the right upper limb through the *right subclavian trunk*; from the right side of the thorax, right lung, right side of the heart, and part of the convex surface of the liver, through the *right bronchomediastinal trunk*. These three trunks frequently open separately in the angle of union of the two veins (fig. 781).

Applied Anatomy.—Although blockage of the thoracic duct is usually the result of its invasion in the spread of malignant disease, no signs or symptoms arise because many alternative routes are available for the passage of chyle to the venous circulation. Extreme blockage of the multiple pathways may occasionally occur, e.g. in filariasis, and cause chylous effusions into the peritoneal cavity or pleurae, nevertheless such effusions are more likely to result from rupture of the duct either from trauma, surgical accidents or from a malignant disease such as lymphosarcoma. The root of the neck and the intrathoracic portion of the duct are the common sites of the injury. Ligature of the damaged vessel is always successful in non-malignant cases.

THE LYMPHATIC DRAINAGE OF THE HEAD AND NECK *

The lymph nodes of the head and neck comprise a terminal group and a number of intermediary, outlying groups. The terminal group is closely associated with the carotid sheath and is named the *deep cervical group*. All the lymph vessels of the head and neck drain into this group, either directly from the tissues themselves, or indirectly after passing through one of the outlying groups. The efferents of the deep cervical lymph nodes form the *jugular trunk*, which, on the right side, may end in the junction of the internal jugular and subclavian veins or may join the right lymphatic duct; on the left side, it usually enters the thoracic duct, although it may join either the internal jugular or the subclavian vein.

THE DEEP CERVICAL LYMPH NODES

The deep cervical lymph nodes are found lying along the carotid sheath from the base of the skull to the root of the neck. They may be subdivided into (1) a superior and (2) an inferior group, both of which receive *afferents* direct from the tissues themselves as well as from the outlying, intermediary groups.

(1) The **superior deep cervical lymph nodes** (fig. 782) lie in close relationship with the upper part of the internal jugular vein. Most of them are hidden by the sternomastoid, but a few extend beyond the borders of the muscle. One group, which comprises one large and several small nodes, is placed in the triangular area bounded by the posterior belly of the digastric, the facial vein, and the internal jugular vein, and is termed the *jugulo-digastric group*; it is associated particularly with the lymph drainage of the tongue.

Efferents from the upper deep cervical lymph nodes pass to the lower deep cervical group as well as to the jugular trunk.

(2) The **inferior deep cervical lymph nodes** are situated under cover of the lower part of the sternomastoid, and extend also into the subclavian triangle, where they are closely related to the brachial plexus and the subclavian vessels. One node of this group lies on, or just above the intermediate tendon of the omohyoid muscle; it is called the *jugulo-omohyoid lymphatic node* (Jamieson and Dobson) † and is concerned especially with the drainage of the tongue (p. 889). The efferents from the lower deep cervical lymph nodes join the jugular trunk.

From the point of view of their lymphatic drainage the tissues of the head and neck can conveniently be considered in two groups, viz.: (a) The superficial tissues and (b) the deeper structures, including the viscera.

A. LYMPHATIC DRAINAGE OF THE SUPERFICIAL TISSUES OF THE HEAD AND NECK (fig. 783)

Most of the superficial tissues are drained by vessels which go first to outlying groups of lymphatic nodes, and the efferents from these pass to the deep cervical lymph nodes. Some of the lymph, however, may pass directly to the deep cervical nodes.

The outlying groups concerned in the drainage of the superficial tissues are:

<i>In the head.</i>	<i>In the neck.</i>
Occipital.	Submandibular.
Retro-auricular (Mastoid).	Submental.
Parotid.	Anterior cervical.
Buccal (Facial).	Superficial cervical.

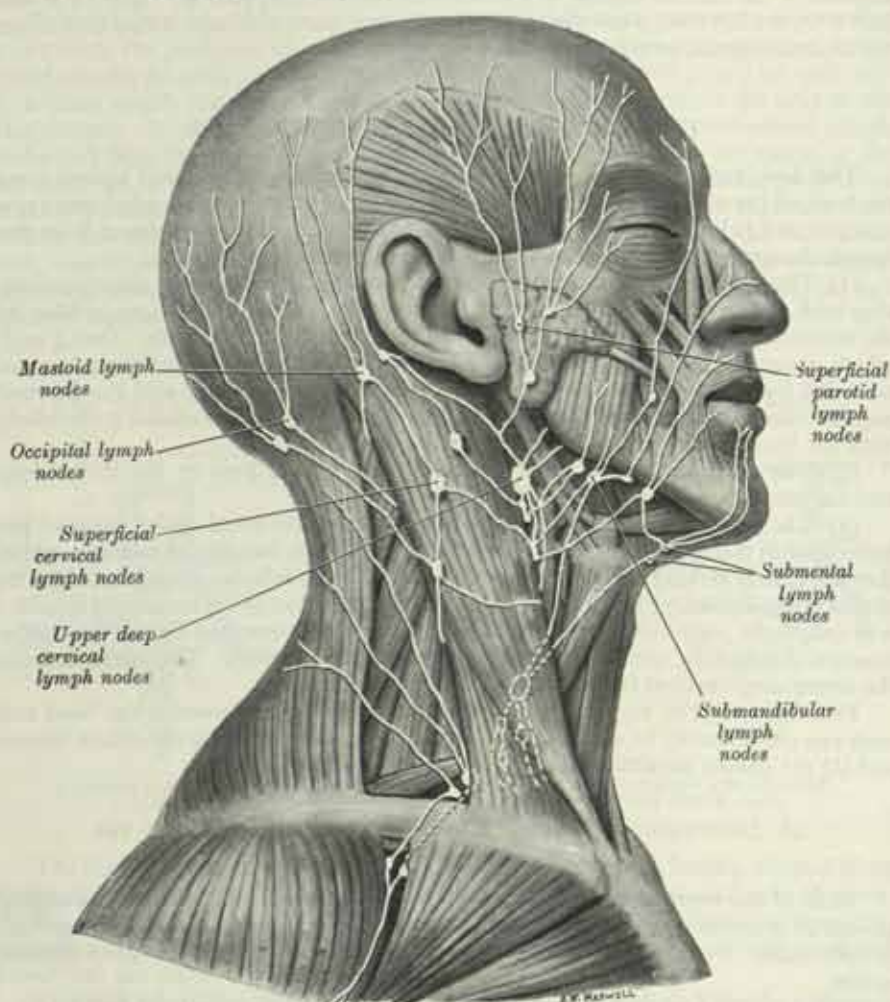
1. **Lymphatic drainage of the scalp and ear.**—(i) The lymph vessels from the frontal region just above the root of the nose drain into the submandibular group of lymph nodes (fig. 782) and will be considered with the lymphatics of the face.

* In this and the following sections only the larger and more constant groups of lymph nodes are included. For a detailed description and references to the literature, consult *Anatomie des Lymphatiques de l'homme*, by H. Rouvière. Masson et Cie, Paris, 1932.

† J. K. Jamieson and J. F. Dobson, "The Lymphatics of the Tongue," *British Journal of Surgery*, vol. viii, No. 29, 1920.

(ii) The vessels from the rest of the forehead, from the temporal region of the scalp, and from the upper half of the lateral surface of the auricle and the anterior wall of the external auditory meatus drain into the *superficial parotid lymph nodes*, which lie immediately in front of the tragus, on, or deep to, the fascial investment of the parotid gland. These nodes receive also the lateral lymph vessels from the eyelids and those from the skin over the zygomatic bone. Their efferent vessels pass to the upper deep cervical lymph nodes.

FIG. 782.—The superficial lymph glands and lymph vessels of the head and neck.



(iii) A strip of the scalp above the auricle, the upper half of the cranial surface and margin of the auricle, and the posterior wall of the external auditory meatus are drained by vessels which pass, some to the upper deep cervical lymph nodes and others to the retro-auricular group.

The *retro-auricular lymph nodes* (fig. 782) are placed superficial to the mastoid insertion of the Sternomastoid muscle, and deep to the Auricularis posterior. Their efferents pass to the upper deep cervical lymph nodes.

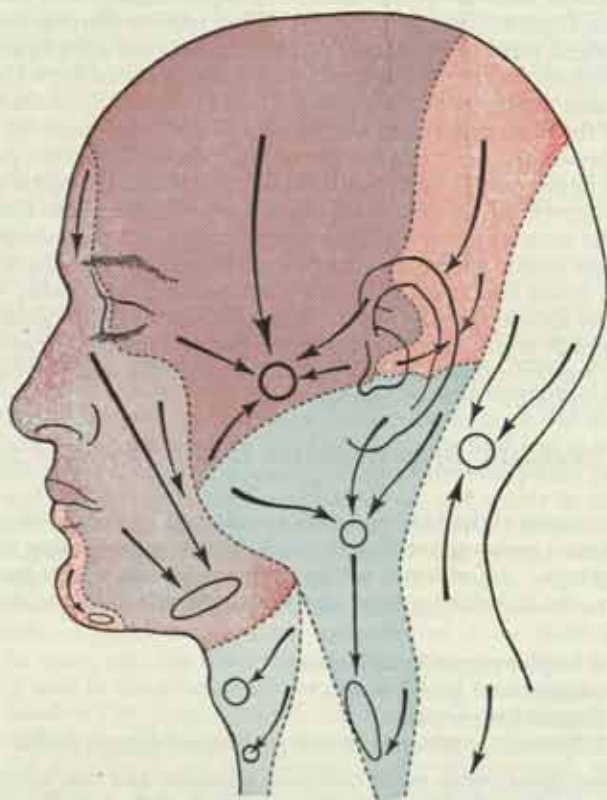
(iv) The lobule of the auricle, the floor of the external auditory meatus, and the skin over the angle of the jaw and the lower part of the parotid region are drained by vessels which may pass to the superficial cervical group of lymph nodes or to the upper deep cervical group. The *superficial cervical lymph nodes* are placed along the external jugular vein superficial to the Sternomastoid. Some of the efferents from this group pass round the anterior border of the Sternomastoid to reach the upper

deep cervical lymph nodes; others follow the external jugular vein and join the lower deep cervical lymph nodes in the subclavian triangle.

(v) The occipital region of the scalp is drained partly by vessels which pass to the occipital group of lymph nodes, and partly by a trunk which descends along the posterior border of the Sternomastoid to end in the lower deep cervical lymph nodes. The *occipital lymph nodes* are placed in the upper angle of the posterior triangle, superficial to the attachment of the Trapezius to the occipital bone.

2. Lymphatic drainage of the face.—(i) The lymph vessels draining the eyelids and conjunctiva commence in a superficial plexus beneath the skin and in a deep plexus in front of and behind the tarsi; these plexuses communicate with one

FIG. 783.—The areas of lymphatic drainage of the superficial tissues of the head and neck.



another and medial and lateral sets of vessels arise from them. The lymph vessels of the lateral set drain the whole thickness of the upper lid with the exception of the skin over its medial part; they also drain the whole thickness of the lateral half of the lower lid and all the ocular conjunctiva. They pass laterally from the lateral commissure to end in the superficial parotid lymph nodes and also in the *deep parotid lymph nodes*, which are embedded in the substance of the parotid salivary gland. The deep parotid lymph nodes receive vessels also from the middle ear (p. 889). The lymph vessels of the medial set drain the skin over the medial part of the upper eyelid, the whole thickness of the medial half of the lower lid, and the caruncula lacrimalis. Following the course of the facial vein they end in the submandibular group of lymph nodes.

The *submandibular lymph nodes* (figs. 782, 783) are placed beneath the deep cervical fascia in the submandibular triangle. They are usually three in number, one at the anterior end of the submandibular salivary gland, and one in front of, and another behind the facial artery where it reaches the mandible. Additional members of this group are often found embedded in the submandibular salivary gland or on its deep surface. The submandibular lymph nodes receive afferents from a wide area,

including vessels from the submental, buccal and lingual groups of lymph nodes; their efferents pass to both the upper and lower deep cervical lymph nodes.

(ii) The external nose, cheek and upper lip, and the lateral part of the lower lip send their lymph to the submandibular lymph nodes. These vessels may have along their course a few *buccal lymph nodes* lying in relation to the facial vein. The mucous membrane covering the oral surfaces of the lips and cheeks is drained by vessels which end also in the submandibular lymph nodes. The lymph from the lateral part of the cheek drains into the parotid lymph nodes, whilst that from the skin over the root of the nose and the central part of the forehead just above this drains partly into the parotid lymph nodes, and partly, along the facial lymphatics, into the submandibular lymph nodes.

(iii) The central part of the lower lip, together with the floor of the mouth and the tip of the tongue, is drained by vessels which pass to the submental group of nodes. The *submental lymph nodes* are placed on the Mylohyoid muscle between the anterior bellies of the two Digastric muscles (fig. 784). They receive afferents from both sides of the median plane, some of the vessels decussating over the symphysis of the mandible; their efferents pass to the submandibular and jugulo-omohyoid lymph nodes.

3. **Lymphatic drainage of the neck.**—Many of the vessels draining the superficial tissues of the neck pass round the borders of the Sternomastoid to either the upper or the lower deep cervical lymph nodes. Some, however, pass from the region over the upper part of the Sternomastoid muscle and the posterior triangle of the neck to the superficial cervical and occipital lymph nodes. The lymph from the upper part of the anterior triangle of the neck is drained into the submandibular and submental lymph nodes, whilst the vessels from the skin of the anterior part of the neck below the hyoid bone pass to the *anterior cervical lymph nodes*, which are associated with the anterior jugular veins. The efferents from this group pass to the deep cervical lymph nodes of both sides of the neck: they pass to infrahyoid, prelaryngeal, and pretracheal nodes (*vide infra*). One of the anterior cervical lymph nodes often occupies the suprasternal space (p. 566).

B. LYMPHATIC DRAINAGE OF THE DEEPER TISSUES OF THE HEAD AND NECK

The deeper tissues of the head and neck are drained by vessels which pass to the deep cervical lymph nodes either directly, or indirectly after passing through one of the outlying groups. In addition to the outlying groups which have been considered already, the following groups also are concerned with the drainage of the deeper tissues, viz.:

- The retropharyngeal lymph nodes.
- The paratracheal lymph nodes.
- The lingual lymph nodes.
- The infrahyoid, prelaryngeal and pretracheal lymph nodes.

The *retropharyngeal lymph nodes* comprise a median and two lateral groups, the former near the median plane, and the latter in front of the lateral mass of the atlas along the lateral border of the Longus capitis muscle. They all lie in the interval between the fascia covering the pharynx and the prevertebral fascia. Their efferents pass to the upper deep cervical lymph nodes.

The *paratracheal lymph glands* on each side are situated lateral to the trachea and œsophagus, along the course of the recurrent laryngeal nerve. Efferents from this group pass to the deep cervical lymph nodes.

The *infrahyoid, prelaryngeal and pretracheal lymph glands* lie deep to the investing layer of the deep cervical fascia. They receive some of their afferents from the anterior cervical lymph nodes and their efferents join the deep cervical groups. The lymph nodes of the infrahyoid group are placed on the front of the thyrohyoid membrane; those of the prelaryngeal group lie on the conus elasticus and the cricovocal membrane; the pretracheal lymph nodes lie in front of the trachea in close relation with the inferior thyroid veins.

The *lingual lymph nodes* are small and inconstant. They are found on the Hyoglossus muscle and between the two Genioglossi.

1. **The lymphatic drainage of the nasal cavity, nasopharynx and middle ear.**—The lymphatics of the nasal cavity can be injected from the subarachnoid space, through communications which exist along the course of the olfactory nerves.

The lymph vessels from the anterior part of the nose pass superficially to join those draining the skin covering the nose and end in the submandibular lymph nodes. The remainder of the nasal cavity, the paranasal sinuses, the nasopharynx, and the pharyngeal end of the auditory tube are drained by vessels which pass to the upper deep cervical lymph nodes, either directly or after traversing the retropharyngeal lymph nodes. It is probable that the posterior part of the floor of the nose is drained by vessels which enter the parotid group of lymph nodes.

The lymph vessels of the mucous lining of the tympanum and mastoid antrum pass to the parotid or upper deep cervical lymph nodes; those from the tympanic end of the auditory tube probably end in the deep cervical lymph nodes.

2. The lymphatic drainage of the larynx, trachea, and thyroid gland.—

The lymph vessels of the larynx comprise upper and lower groups; on the lateral wall the two systems are distinct one from another, the line of division being the vocal fold; the two systems anastomose on the posterior wall of the larynx. The vessels of the upper set pierce the thyrohyoid membrane, and, accompanying the superior laryngeal vessels, end in the upper deep cervical lymph nodes. The vessels of the lower set either pass between the cricoid cartilage and the first tracheal ring to go directly to the lower deep cervical lymph nodes, or, piercing the cricovocal membrane, pass to the pretracheal and prelaryngeal groups before reaching the deep cervical lymph nodes.

The cervical part of the trachea is drained by vessels which pass to the pretracheal and paratracheal lymph nodes, or directly to the lymph nodes of the lower deep cervical group.

The lymph vessels of the thyroid gland accompany the veins. Vessels of the upper set pass to the deep cervical lymph nodes; those of the lower set to the pretracheal and paratracheal lymph nodes. Some of the vessels may run down into the superior mediastinum and communicate with those of the thymus.

3. The lymphatic drainage of the mouth, teeth, tonsil and tongue.—

(i) *The mouth.*—The vessels of the gums end in the submandibular lymph nodes; those of the hard palate are continuous in front with those of the upper gum, but run backwards to pierce the superior constrictor muscle, and end in the upper deep cervical and retropharyngeal lymph nodes; those of the soft palate pass backwards and laterally and end partly in the retropharyngeal, and partly in the upper deep cervical lymph nodes. The vessels of the anterior part of the floor of the mouth go to the inferior lymph nodes of the upper deep cervical group, either directly or indirectly through the submental lymph nodes; the vessels from the rest of the floor of the mouth pass to the submandibular and upper deep cervical lymph nodes.

(ii) *The teeth.*—Lymph vessels were demonstrated in the pulp of the teeth by Schweitzer* in 1907, and his observations have been confirmed by Dewey and Noyes†. They pass to the submandibular and deep cervical lymph nodes.

(iii) *The tonsil.*—The lymph vessels of the tonsil, usually three to five in number, pierce the buccopharyngeal fascia and the superior constrictor muscle and pass between the stylohyoid and the internal jugular vein to reach the upper deep cervical lymph nodes. Most of them end in the jugulo-digastric lymph nodes; occasionally one or two additional vessels run to small lymph nodes on the lateral side of the internal jugular vein, under cover of the sternomastoid.

(iv) *The tongue* (figs. 784, 785).‡—The lymphatic plexus in the mucous membrane of the tongue is continuous with the intramuscular plexus. The part of the tongue in front of the papillæ vallatæ is drained into marginal and central lymph vessels. The part of the tongue behind the papillæ vallatæ drains into a set of dorsal lymph vessels.

1. *Marginal vessels.*—The lymph vessels from the tip of the tongue, and region of the frenulum, descend under the mucous membrane and end in widely distributed lymph nodes.

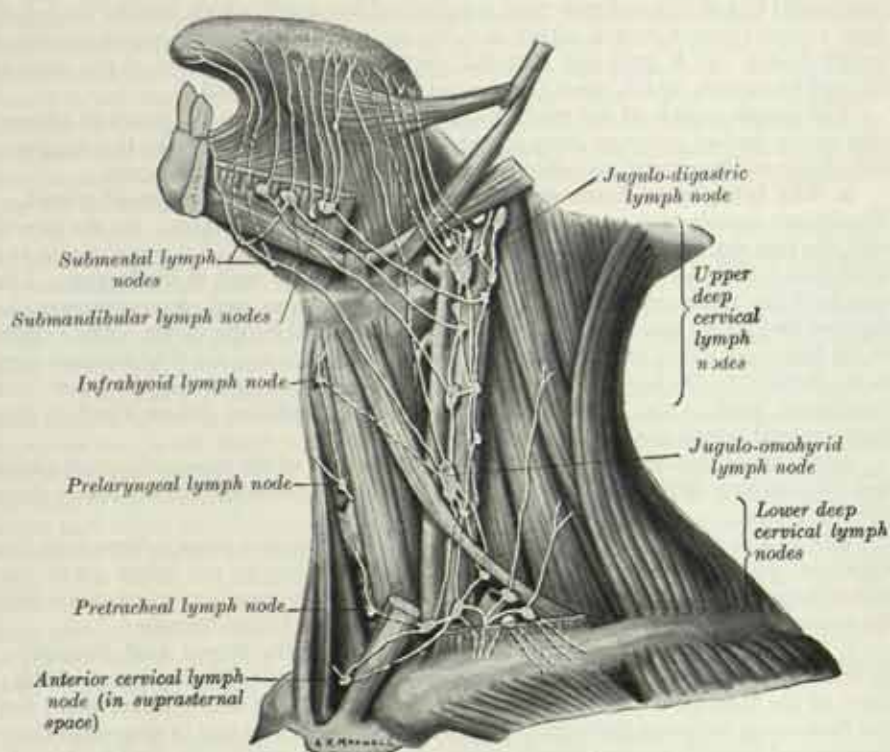
(a) Vessels pierce the origin of the mylohyoid in contact with the periosteum of the mandible; one or two of these vessels enter the submental lymph nodes, and one descends over the hyoid bone to the jugulo-omohyoid lymph node. (It should

* *Archiv für Mikrosk. Anat. u. Entwickl.*, 1907 and 1909.

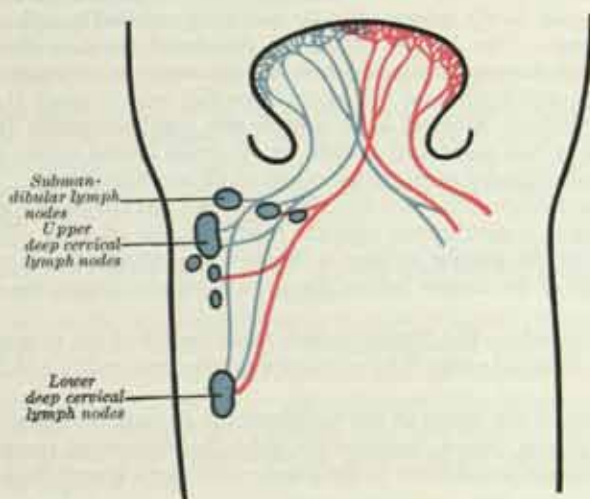
† *Dental Cosmos*, 59, No. 4, 1917.

‡ This description of the lymphatic vessels of the tongue is based on the researches of Jamieson and Dobson (*loc. cit.* p. 885).

FIG. 784.—The lymphatic drainage of the tongue. (After Jamieson and Dobson.)



Note.—The removal of the Sternomastoid muscle has exposed the whole chain of deep cervical lymph nodes.

FIG. 785.—A diagram to show the course of the central lymph vessels of the tongue to the lymph nodes on both sides of the neck. (Jamieson and Dobson.) *British Journal of Surgery*, vol. viii, 1920.

be noted (1) that vessels arising in the plexus on one side of the tongue may cross under the frenulum and end in the lymph nodes of the opposite side, and (2) that the efferent vessels of the submental lymph nodes, which are placed in or near the median plane, pass impartially to either side.)

(b) Some vessels pierce the origin of the mylohyoid, and enter the anterior or the middle submandibular lymph node.

(c) Some vessels pass deeply under the sublingual salivary gland and, accompanying the vena comitans n. hypoglossi, end in the jugulo-digastric lymph nodes. One vessel often descends over or deep to the common tendon of the Digastric to reach the jugulo-omohyoid lymph node.

Some of the lymph vessels from the lateral margin of the tongue pass over the sublingual salivary gland, pierce the Mylohyoid, and end in the submandibular lymph nodes; others pass under the salivary gland and end in the jugulo-digastric or jugulo-omohyoid nodes.

The vessels from the posterior part of the margin of the tongue make their way through the pharyngeal wall to the jugulo-digastric lymph nodes.

2. *Central vessels*.—There is no clear line of demarcation between areas on the surface of the tongue draining into the marginal or into the central vessels. The central lymph vessels descend in the median plane between the Genioglossi. Some turn laterally through the muscles, but the majority appear between their free borders and diverge to the right or left, i.e. the vessels from one side of the tongue may run to the lymph nodes of the opposite side (fig. 785). They follow the lingual blood-vessels, and end in the deep cervical lymph nodes, especially in the jugulo-digastric and jugulo-omohyoid lymph nodes. Some pierce the Mylohyoid and enter the submandibular lymph nodes.

3. *Dorsal vessels*.—The vessels draining the area of the papillae vallatae, and the part of the tongue behind these papillae, run downwards and backwards—those near the median plane may divide and run to both sides. They turn laterally to join the marginal vessels, and all pierce the pharyngeal wall, passing in front of or behind the external carotid artery, to reach the jugulo-digastric and jugulo-omohyoid lymph nodes, or the lymph nodes between them. One vessel may descend behind the hyoid bone, perforate the thyrohyoid membrane, and end in the jugulo-omohyoid lymph node.

4. *The lymphatic drainage of the pharynx and Œsophagus*.—The collecting vessels from the pharynx and Œsophagus pass to the deep cervical lymph nodes either directly, or indirectly through the retropharyngeal or paratracheal lymph nodes. From the region of the epiglottis the lymph vessels run to the infrahyoid lymph nodes.

THE LYMPHATIC DRAINAGE OF THE UPPER LIMB

All the lymph vessels of the upper limb drain into a terminal group of lymph nodes situated in the axilla, either directly from the tissues, or indirectly after passing through an outlying group of lymph nodes. The lymph vessels comprise deep and superficial sets. The deep vessels follow the principal vascular and neurovascular bundles, while the superficial vessels, except in the hand and on the back of the forearm, accompany the superficial veins more or less closely.

The **axillary lymph nodes** (fig. 787), which are the terminal group for the whole of the upper limb, are of large size; they vary from twenty to thirty in number, and may be divided into five groups, which are not sharply demarcated from one another:

1. A *lateral group* (fig. 786) of from four to six lymph nodes lies medial to, and behind, the axillary vein; the afferents of this group drain the whole limb with the exception of that portion whose lymph vessels accompany the cephalic vein. The efferent vessels pass partly to the central and apical groups of axillary lymph nodes, and partly to the lower deep cervical lymph nodes.

2. An *anterior or pectoral group* of four or five lymph nodes lies along the lower border of the Pectoralis minor, in relation with the lateral thoracic vessels. Its afferents drain the skin and muscles of the anterior and lateral walls of the body, above the level of the umbilicus, and the central and lateral parts of the mammary

gland (p. 894); its efferents pass partly to the central, and partly to the apical groups of axillary lymph nodes.

3. A *posterior or subscapular group* of six or seven lymph nodes is placed along the lower margin of the posterior wall of the axilla in the course of the subscapular vessels. The afferents of this group drain the skin and muscles of the lower part of the back of the neck and of the dorsal aspect of the trunk, as low down as the iliac crest; their efferents pass to the apical and to the central group of axillary lymph nodes.

4. A *central group* of three or four large lymph nodes is embedded in the fat near the base of the axilla. It has no special area of drainage, but it receives afferents from all the preceding groups of axillary lymph nodes: its efferents pass to the apical group.

5. An *apical group* of six to twelve lymph nodes is situated partly posterior to the upper portion of the Pectoralis minor and partly above the upper border of this muscle, and extends upwards into the apex of the axilla along the medial side of the axillary vein. The only direct territorial afferents of this group are those which accompany the cephalic vein and one or two which drain the upper and peripheral part of the mammary gland, but it receives the efferents of all the other axillary lymph nodes. The efferent vessels of this group unite to form the *subclavian trunk*, which opens either directly into the junction of the internal jugular and subclavian veins or into the jugular lymphatic trunk; on the left side it may end in the thoracic duct. A few efferents from the apical group usually pass to the lower deep cervical lymph nodes.

The outlying lymph nodes in the upper limb are few in number. They comprise (1) the *supratrochlear group*, (2) the *infraclavicular group* (which are both interposed on the path of the superficial vessels), and (3) a few isolated lymph nodes which are occasionally present along the course of the principal blood-vessels of the arm and forearm.

1. The *supratrochlear lymph nodes*, one or two in number, lie on the deep fascia above the medial epicondyle of the humerus on the medial side of the basilic vein. Their efferents accompany the basilic vein and join the deep lymph vessels.

2. The *infraclavicular lymph nodes*, one or two in number, are found beside the cephalic vein, between the Pectoralis major and the Deltoid, immediately below the clavicle. Their efferents pass through the clavipectoral fascia to reach the apical group of the axillary lymph nodes, or, more rarely, they may pass across the clavicle to reach the lower deep cervical group.

3. Isolated lymph nodes, small in size, are sometimes found in the forearm along the radial, ulnar and interosseous vessels, in the cubital fossa near the bifurcation of the brachial artery, and in the arm along the medial side of the brachial vessels.

The lymphatic drainage of the superficial tissues of the upper limb.—The superficial lymph vessels begin in the lymphatic plexuses in the skin.

In the hand, the meshes of the plexus are much finer on the palmar than on the dorsal surface. The digital plexuses are drained by vessels which run along the borders of the digits to reach the web, where they receive vessels from the distal part of the palm and then pass backwards to reach the dorsal surface of the hand (figs. 786, 788). The rest of the palm is drained by vessels which pass proximally towards the wrist, medially to join vessels along the ulnar border of the hand, and laterally to join those on the thumb. Several collecting vessels from the central part of the palmar plexus unite to form a trunk which winds round the metacarpal bone of the index finger to join the dorsal vessels from the same finger and from the thumb.

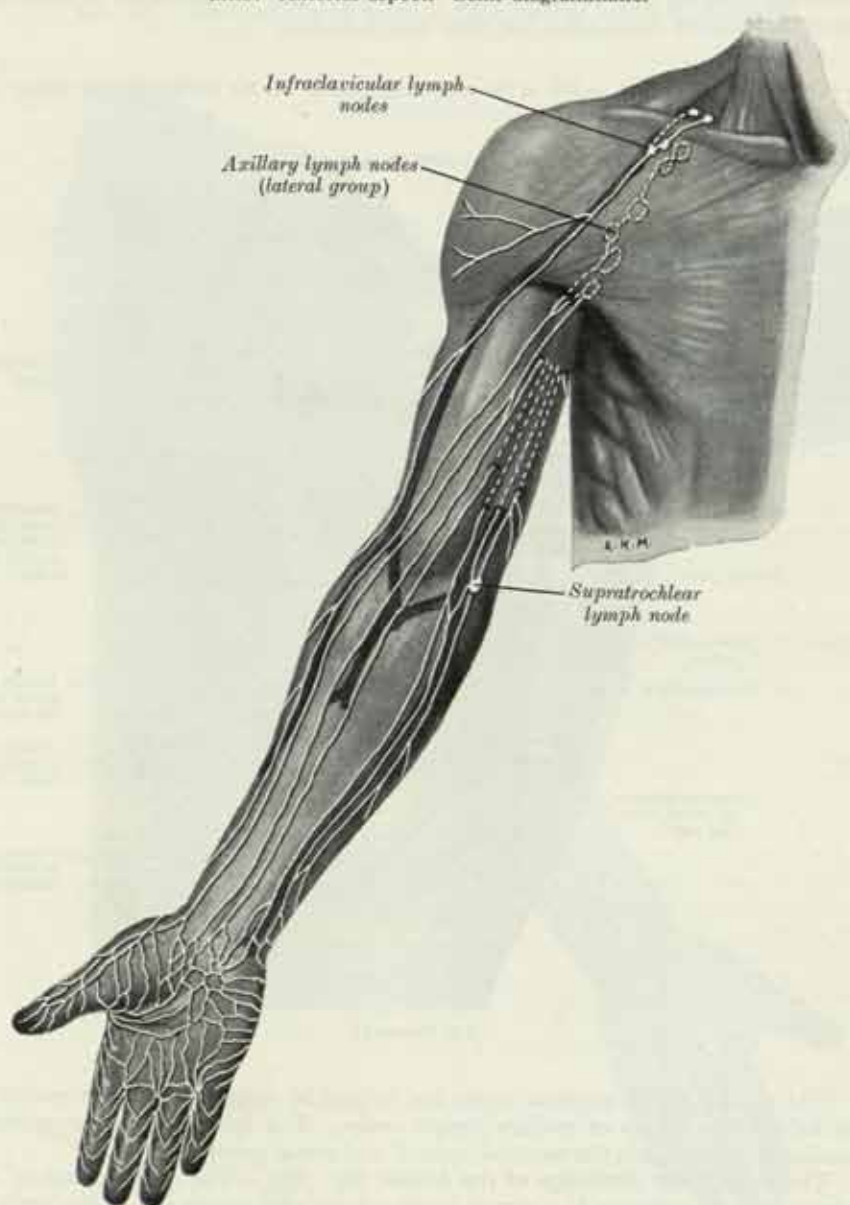
In the forearm and arm, the superficial lymph vessels run, for the most part, in company with the superficial veins. Collecting vessels from the hand pass into the forearm on all aspects of the wrist.

The vessels on the dorsum, after running vertically upwards parallel with one another, finally pass successively round the borders of the limb to join vessels on the front (fig. 788). The vessels on the front of the wrist pass up the forearm parallel with the median antebrachial vein to the cubital region. Beyond this point they follow the medial border of the biceps muscle and, piercing the deep fascia at the anterior axillary fold, they end in the lateral group of axillary lymph nodes.

The vessels on the lateral side of the wrist become associated in the forearm with the cephalic vein. They follow it to the level of the insertion of the Deltoid, where

most of them incline medially to enter the lateral group of axillary lymph nodes ; a few continue with the cephalic vein and end in the infraclavicular nodes. These lateral lymph vessels receive the vessels which wind round the lateral border of the limb from the posterior surface.

FIG. 786.—The lymphatic drainage of the superficial tissues of the upper limb. Anterior aspect. Semi-diagrammatic.



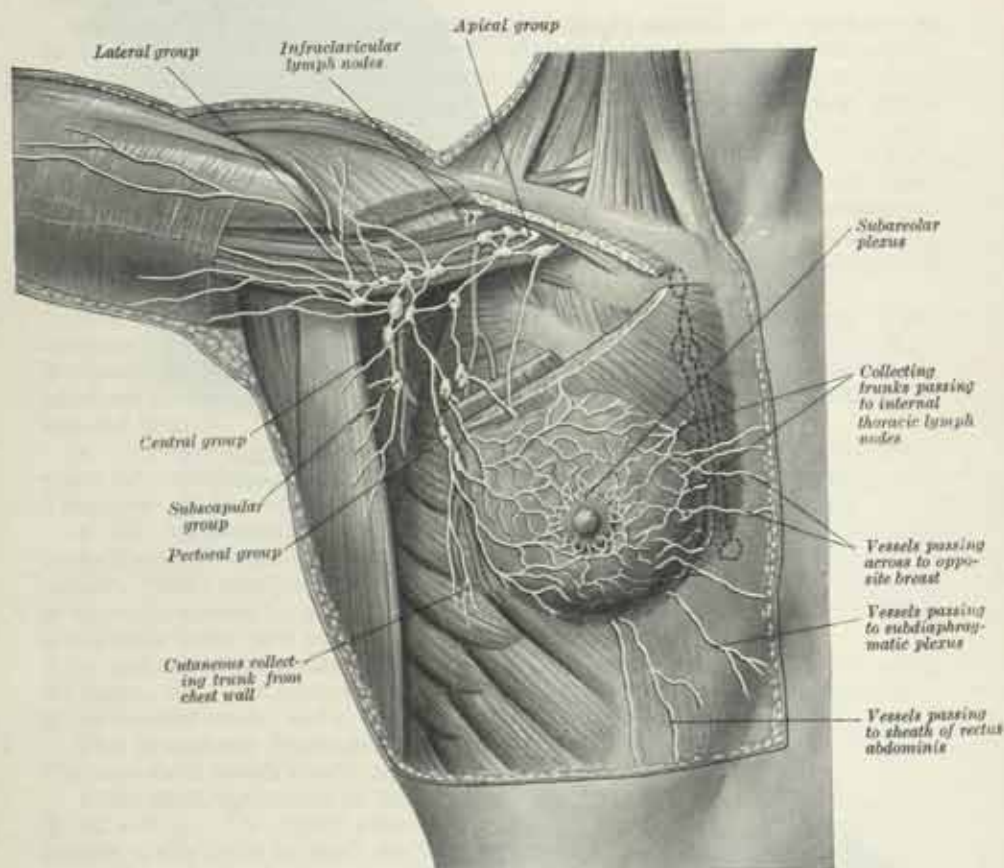
The vessels on the medial side of the wrist follow the basilic vein in the forearm. Just above the elbow some of them end in the supratrochlear lymph nodes. The efferents from these, together with the medial vessels which have not ended in the supratrochlear nodes, pierce the deep fascia with the basilic vein, and end in the lateral group of axillary nodes or join the deep vessels. The vessels which wind round the medial border of the limb from the back join those of this medial set.

The collecting vessels from the front and back of the deltoid region pass respectively round the anterior and posterior axillary folds to end in the axillary lymph

nodes. The skin over the scapular region is drained by vessels which either end in the subscapular group of axillary lymph nodes, or follow the transverse cervical vessels and end in the lower deep cervical lymph nodes.

The lymphatic drainage of the deep tissues of the upper limb.—The deep lymph vessels follow the main bundles of vessels and nerves (radial, ulnar, interosseous and brachial) and end in the lateral axillary lymph nodes. They are less numerous than the superficial vessels, with which they communicate at intervals. Along their course there are a few deep lymph nodes.

FIG. 787.—The lymph vessels of the mammary gland, and the axillary lymph nodes. Semi-diagrammatic.



A. K. MAXWELL

The muscles of the scapular region are drained by vessels which pass mainly to the subscapular group of axillary lymph nodes. The lymph from the pectoral muscles is drained into the pectoral, central and apical groups.

The lymphatic drainage of the breast (fig. 787).—The lymph vessels of the mammary gland originate in a plexus in the interlobular spaces and in the walls of the lactiferous ducts. Those from the central part of the gland enter an intricate plexus which is situated beneath the areola. This plexus also receives the lymph vessels from the skin over the central part of the gland, and from the areola and nipple.

The efferent lymph vessels from the greater part of the mammary gland anastomose with the lymphatic plexus in the fascia on the Pectoralis major muscle, and subsequently end in the pectoral group of axillary lymph nodes; one vessel from the upper part of the gland pierces the Pectoralis major, and ends in the apical group of axillary lymph nodes. Through this fascial plexus also the lymph vessels from the medial part of the gland communicate with (a) the internal thoracic

lymph nodes (p. 909), and (b) with the lymph vessels of the opposite breast. The lymph vessels from the lower and medial parts of the mammary gland anastomose with a lymphatic plexus on the sheath of the upper part of the rectus abdominis, and on the front of the linea alba between the xiphoid process of the sternum and the seventh costal cartilage ; although no direct communications between this plexus

FIG. 788.—The lymphatic drainage of the superficial tissues of the upper limb. Posterior aspect. Semi-diagrammatic.



and the lymph vessels in the subperitoneal areolar tissue have been demonstrated by injection, the clinical and pathological investigations of W. Sampson Handley * leave no doubt that such exist.

Applied Anatomy.—Enlargement of the axillary lymph nodes is very often found in malignant disease and also in infective processes implicating the upper part of the

* *Cancer of the Breast and its Treatment*, 2nd edition, 1922, and "The Breast", *Choyce's System of Surgery*, 3rd edition, vol. i, 1932.

back and shoulder, the front of the chest and mammary gland, the upper part of the front and side of the abdomen, or the hand, forearm, and arm.

In operations for cancer of the breast the fascia covering the Pectoralis major and the adjoining muscles is removed over a wide area on account of the connexions and ramifications of the lymphatic plexus which it contains. In addition the axillary lymph nodes, the sternocostal head of Pectoralis major and, frequently, the Pectoralis minor are taken away, in the endeavour to ensure, as far as possible, the complete removal of affected lymph vessels.

THE LYMPHATIC DRAINAGE OF THE LOWER LIMB

All the lymph from the lower limb, with the exception of that from the gluteal and ischial regions, traverses a terminal group of lymph nodes in the groin. Before reaching these terminal nodes the lymph may have passed through outlying, intermediary lymph nodes, which, however, are less numerous in the lower limb than they are in other parts of the body.

The terminal lymph nodes are named the inguinal lymph nodes, and they are in two sets: superficial and deep.

The **superficial inguinal lymph nodes** (fig. 789) are themselves arranged in two groups, upper and lower. The *upper group*, usually 5 or 6 in number, forms a chain immediately below the inguinal ligament. The lateral members of the group receive afferent vessels from the gluteal region and from the adjoining part of the anterior abdominal wall below the umbilicus. The medial members of the group receive the superficial lymph vessels from the external genitalia (including in the female the vagina below the hymen), from the lower part of the anal canal and the circumanal region, from the adjoining part of the anterior abdominal wall below the umbilicus and uterine lymph vessels which run along the round ligament of the uterus.

The *lower group*, usually four or five in number, is disposed vertically along the terminal part of the great saphenous vein. They receive all the superficial lymph vessels of the lower limb, with the exception of those from the back and lateral side of the calf of the leg.

All the superficial inguinal lymph nodes send their *efferents* to the external iliac lymph nodes, some traversing the femoral canal, others passing in front of or lateral to the femoral vessels. In addition numerous vessels connect the individual nodes one with another.

The **deep inguinal lymph nodes** vary from one to three in number, and are placed deep to the fascia lata, on the medial side of the femoral vein. When three are present, the lowest is situated just below the junction of the great saphenous and femoral veins, the middle in the femoral canal, and the highest in the lateral part of the femoral ring. The middle one is the most inconstant, but the highest is frequently absent. They receive as afferents the deep lymph vessels which accompany the femoral vessels, the lymph vessels from the glans penis (or glans clitoridis), and, possibly, a few of the efferents from the superficial inguinal lymph nodes; their efferents pass through the femoral canal to the external iliac lymph nodes.

The outlying, intermediary lymph nodes are few in number and are all deeply placed. Except for a single node which is sometimes present on the upper part of the interosseous membrane of the leg in relation with the anterior tibial vessels, they are restricted to a single group found in the popliteal fossa.

The **popliteal lymph nodes** (fig. 790), small in size and six or seven in number, are embedded in the fat contained in the popliteal fossa. One lies near the termination of the small saphenous vein, and drains the region from which this vein derives its tributaries. Another is placed between the popliteal artery and the posterior surface of the knee-joint; it receives the lymph vessels from the knee-joint together with those which accompany the genicular arteries. The remainder lie at the sides of the popliteal vessels, and receive as afferents the trunks which accompany the anterior and posterior tibial vessels. The efferents of the popliteal lymph nodes ascend in close relation with the femoral vessels to the deep inguinal lymph nodes, but a few may accompany the great saphenous vein and end in the superficial inguinal lymph nodes.

FIG. 789.—The lymphatic drainage of the superficial tissues of the lower limb. Antero-medial aspect. Semi-diagrammatic.

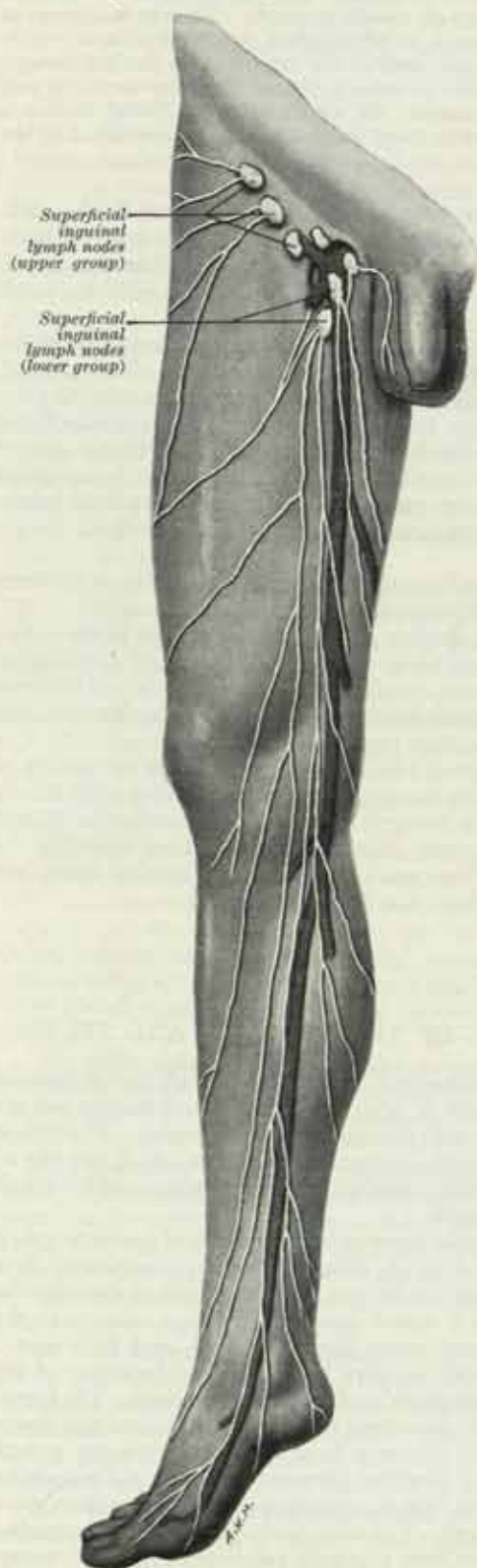
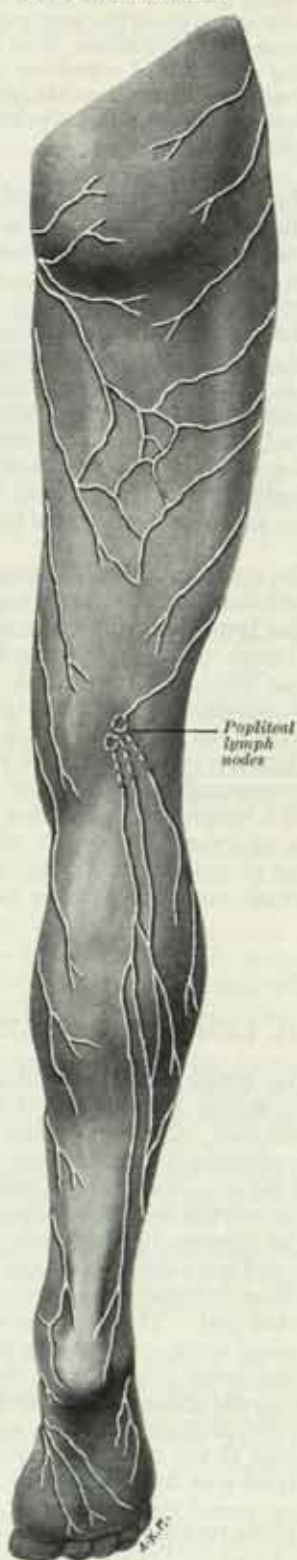


FIG. 790.—The lymphatic drainage of the superficial tissues of the lower limb. Posterior aspect. Semi-diagrammatic.



Applied Anatomy.—Inflammation and suppuration of the popliteal lymph nodes are most commonly due to a lesion on the lateral side of the heel.

The superficial inguinal lymph nodes frequently become enlarged in diseases implicating the parts from which their lymph vessels originate. Thus in malignant or syphilitic affections of the prepuce and penis, or labia majora, in cancer of the scrotum, in abscess in the perineum, anus and lower part of the vagina, or in similar diseases affecting the skin and superficial structures in those parts, or the infra-umbilical part of the abdominal wall, or the gluteal region, the upper group of lymph nodes is almost invariably enlarged, the lower group being implicated in diseases affecting the lower limb.

The lymphatic drainage of the superficial tissues of the lower limb.—The superficial lymph vessels begin in the lymphatic plexuses beneath the skin. Collecting vessels leave the foot in two sets—a medial set, whose vessels follow the general course of the great saphenous vein, and a lateral set, associated with the small saphenous vein.

The vessels of the *medial group* are larger and more numerous than those of the lateral group and begin on the tibial side of the dorsum of the foot. They ascend, some in front of the medial malleolus and others behind it, and accompany the great saphenous vein to the groin, where they end in the lower group of the superficial inguinal lymph nodes. The vessels of the *lateral group* begin on the fibular side of the dorsum of the foot. Some of them cross the front of the leg to join the vessels of the medial group and so reach the lower group of the superficial inguinal lymph nodes; others accompany the small saphenous vein and end in the popliteal lymph nodes.

The superficial lymph vessels of the buttock pass round to the front of the limb and terminate in the upper group of the superficial inguinal lymph nodes.

The lymphatic drainage of the deeper tissues of the lower limb.—The deep lymph vessels accompany the main blood-vessels of the limb and so comprise anterior tibial, posterior tibial, peroneal, popliteal and femoral sets. The deep lymph vessels of the foot and leg are interrupted by the popliteal lymph nodes, but those from the thigh pass direct to the deep inguinal lymph nodes.

The deep lymph vessels of the gluteal and ischial regions follow the course of the corresponding blood-vessels. Those accompanying the superior gluteal vessels end in a lymph node which lies on the intrapelvic portion of the superior gluteal artery, near the upper border of the greater sciatic foramen. Those following the inferior gluteal vessels traverse one or two small lymph nodes which lie below the piriformis muscle, and end in the internal iliac lymph nodes.

THE LYMPHATIC DRAINAGE OF THE ABDOMEN AND PELVIS

The lymph from most of the abdominal wall and from all the abdominal viscera except a small part of the liver is returned to the blood-stream *viâ* the thoracic duct. The lymph vessels run with the corresponding arteries. The lymph nodes comprise a large number of outlying, intermediary groups which are placed along the arteries concerned, and a smaller number of terminal groups which are all in close relation with the abdominal aorta.

The **lumbar lymph nodes** comprise three principal groups of terminal lymph nodes and one subsidiary group, each of which, though not sharply separated from the others topographically, nevertheless has its own particular area of drainage for the most part. These four groups are named according to their relation to the abdominal aorta, viz., pre-aortic, lateral aortic (right and left), and retro-aortic. The pre-aortic group drains the viscera supplied by the ventral branches of the aorta, i.e. the abdominal part of the alimentary canal and its derivatives. The lateral aortic groups drain the viscera and other structures supplied by the lateral and dorsal branches of the aorta and receive the efferents from the large, outlying groups associated with the iliac arteries. They therefore constitute the terminal groups for the suprarenal glands, kidneys, ureters, testes, ovaries, pelvic viscera (apart from the gut) and the posterior abdominal wall. The retro-aortic group has no particular area of drainage. Although it may have been primarily associated with the drainage

of the posterior abdominal wall, it may be regarded as being formed by outlying members of both lateral aortic groups.

A. THE PRE-AORTIC LYMPH NODES AND THEIR AREA OF DRAINAGE

The **pre-aortic lymph nodes** lie in close relationship with the anterior surface of the abdominal aorta. They receive lymph from the outlying, intermediary lymph glands associated with the subdiaphragmatic part of the alimentary canal, the pancreas, liver and spleen. Their efferents unite to form the *intestinal trunk*, which enters the cisterna chyli. They are divisible into celiac, superior mesenteric and inferior mesenteric groups, which are in intimate relationship with the origins of the arteries of the same names.

In the alimentary canal the lymph vessels begin as minute subepithelial radicles, blind at one end but opening at the other into a fine *periglandular plexus*. In the small intestine a central lacteal occupies each villus. From the periglandular plexus vessels pierce the muscularis mucosae and join the *submucous plexus*, efferents from which pass through the muscular coat, where they anastomose more or less freely with vessels draining the muscular coat. The submucous plexus is also joined by vessels from the lymph-spaces at the bases of the solitary lymph nodules. The lymphatics of the intestinal muscle drain into a plexus of vessels found mainly between the longitudinal and circular coats. The collecting vessels from both sets leave the gut by piercing the muscle and entering larger vessels which follow the arteries in the mesentery.

The collecting vessels from the alimentary canal pass through outlying groups of lymph nodes before reaching the pre-aortic group.

1. **The celiac lymph nodes and their areas of drainage.**—The **celiac lymph nodes** lie on the front of the abdominal aorta close to the origin of the celiac artery. They are the terminal group for the stomach, duodenum, liver, gall bladder, pancreas and spleen, and their afferents are derived from the outlying lymph nodes which are placed along the branches of the celiac artery. Of these there are, therefore, three main sets, viz.—gastric, hepatic and pancreaticosplenic.

(i) The **gastric lymph nodes** (figs. 791, 792) consist of three sets, left gastric, right gastro-epiploic and pyloric.

The **left gastric lymph nodes** lie along the left gastric artery and are divisible into three groups, viz.: (a) *upper*, on the stem of the artery; (b) *lower*, associated with the descending branches of the artery along the cardiac half of the lesser curvature of the stomach, between the two layers of the lesser omentum; and (c) *paracardial*, disposed in a manner comparable to a chain of beads around the cardiac orifice of the stomach (Jamieson and Dobson).^{*} They receive their afferents from the stomach; their efferents pass to the celiac group of pre-aortic lymph nodes.

The **right gastro-epiploic lymph nodes**, four to seven in number, lie between the two layers of the greater omentum along the pyloric half of the greater curvature of the stomach in relation with the vessels of the same name. They receive afferents from the stomach; their efferents mostly pass to the pyloric lymph nodes.

The **pyloric lymph nodes** (subpyloric lymph glands of Jamieson and Dobson), four or five in number, lie in close relation to the bifurcation of the gastro-duodenal artery, in the angle between the superior and descending parts of the duodenum; an outlying member of this group is sometimes found above the duodenum on the right gastric artery. They receive afferents from the pyloric part of the stomach, the first part of the duodenum, and the right gastro-epiploic lymph nodes; their efferents end in the celiac group.

(ii) The **hepatic lymph nodes** (fig. 791) are related to the stem of the hepatic artery, and extend upwards along the bile-duct, between the two layers of the lesser omentum, as far as the porta hepatis; one member of this group, termed the *cystic lymph node*, is placed near the neck of the gall-bladder. The lymph nodes of the hepatic chain receive afferents from the stomach, duodenum, liver, gall-bladder, and pancreas; their efferents join the celiac group.

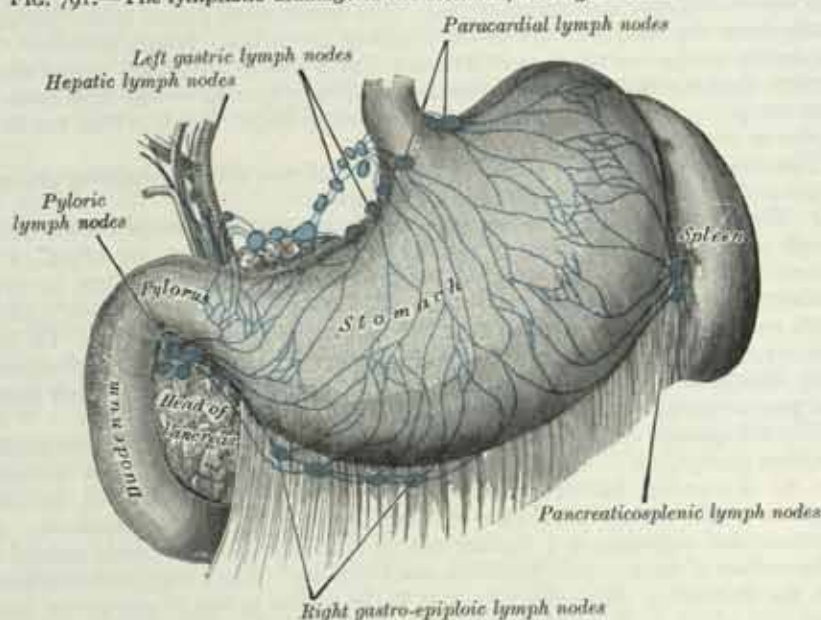
(iii) The **pancreaticosplenic lymph nodes** (fig. 792) accompany the splenic artery, and are situated in relation to the posterior surface and upper border of the

^{*} J. K. Jamieson and J. F. Dobson, *Lancet*, April 20th and 27th, 1907.

pancreas; one or two members of this group are found in the gastrosplenic ligament.* Their afferents are derived from the stomach, spleen, and pancreas; their efferents join the celiac group.

(a) *The lymphatic drainage of the stomach and duodenum.*—The lymph vessels of the stomach (figs. 791, 792) are continuous at the cardiac orifice with those of the œsophagus, and at the pylorus with those of the duodenum. They follow the blood-vessels for the most part, and may be arranged in four sets. Vessels of the first set accompany the branches of the left gastric artery, receive tributaries from a large area on both surfaces of the stomach, and terminate in the left gastric lymph nodes. Those of the second set drain the fundus and body of the stomach on the left of a line drawn vertically from the œsophagus; they lie, more or less closely, along the short gastric and left gastro-epiploic vessels and end in the pancreaticosplenic lymph nodes. Vessels of the third set drain the right part of the greater curvature as far as the pyloric portion, and end in the right gastro-epiploic lymph nodes, the efferents of which pass to the pyloric group. Those of the fourth set drain the pyloric portion and pass to the hepatic, pyloric, and left gastric

FIG. 791.—The lymphatic drainage of the stomach, etc. (Jamieson and Dobson.)



lymph nodes. Although the vessels of these sets communicate with one another, their valves are arranged so that the lymph flow is directed from the right part of the stomach towards the lesser curvature and from the left part towards the greater curvature.†

The lymph vessels of the duodenum comprise an anterior and a posterior set, which open into a series of small pancreaticoduodenal lymph nodes, on the anterior and posterior parts of the groove between the head of the pancreas and the duodenum. The efferents of these glands run in two directions, upwards to the hepatic lymph nodes, and downwards to the pre-aortic lymph nodes around the origin of the superior mesenteric artery.

(b) *The lymphatic drainage of the liver and gall-bladder.*—The collecting vessels from the liver are divisible into two main groups—superficial and deep.

The superficial lymph vessels of the liver run in the subserous areolar tissue over the whole surface of the organ. They drain in four directions. (1) From the middle part of the posterior surface, from the caudate lobe, from the posterior part of the convex surfaces of both lobes near the attachment of the falciform ligament, and from the posterior part of the inferior surface of the right lobe the vessels accompany

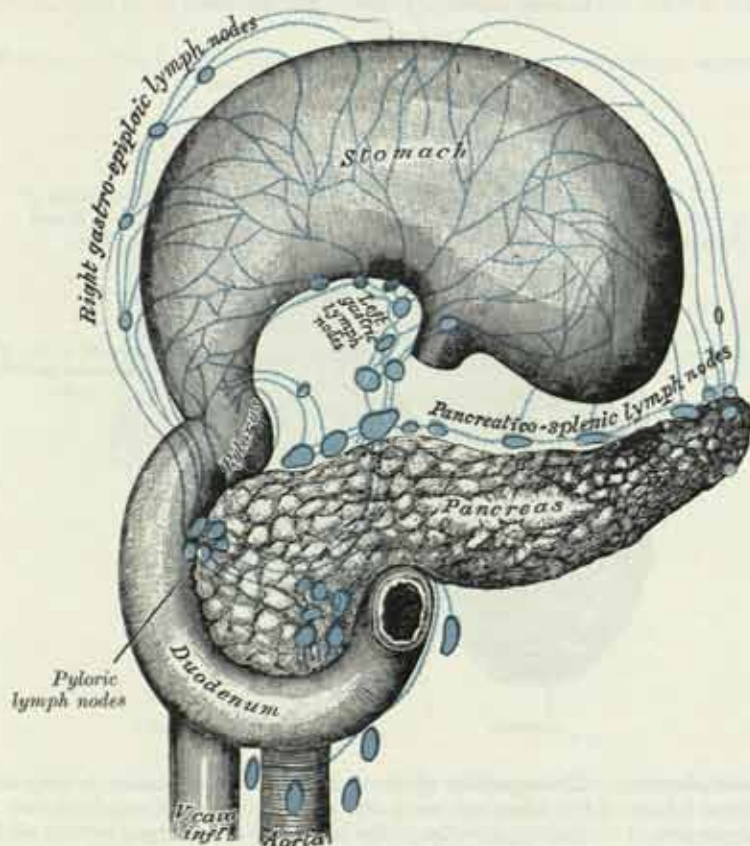
* J. K. Jamieson and J. F. Dobson, *Lancet*, April 20th and 27th, 1907.

† J. H. Gray, *J. Anat.*, 71, 1937.

the inferior vena cava and end in nodes round the terminal part of that vessel. (2) The vessels from the remainder of the inferior surface, and from the anterior part of the convex surface of both lobes near the attachment of the falciform ligament, converge on the porta hepatis and end in the hepatic group of lymph nodes. (3) From the posterior part of the left lobe a few vessels pass towards the œsophageal opening in the diaphragm and end in the paracardial lymph nodes. (4) From the remainder of the convex surface of the right lobe one or two trunks accompany the phrenic artery across the right crus of the Diaphragm and end in the celiac lymph nodes.

The *deep lymph vessels* of the liver join one another to form ascending and descending trunks. The ascending trunks accompany the hepatic veins and,

FIG. 792.—The lymph vessels and glands of the stomach, etc. The stomach has been turned upwards. (Jamieson and Dobson.)



passing through the vena caval opening in the diaphragm, end in the lymph nodes round the termination of the inferior vena cava. The descending trunks emerge from the porta hepatis and end in the hepatic lymph nodes.

The collecting vessels from the gall-bladder pass to the cystic lymph node and the hepatic lymph nodes; those from the bile-ducts end in the hepatic lymph nodes alongside the bile-duct and in the upper pancreaticosplenic lymph nodes.

(c) *The lymphatic drainage of the pancreas.*—The lymph vessels of the pancreas follow the course of its blood-vessels. Most of them end in the pancreaticosplenic lymph nodes, but some end in the lymph nodes along the pancreaticoduodenal vessels and others in the superior mesenteric group of the pre-aortic nodes.

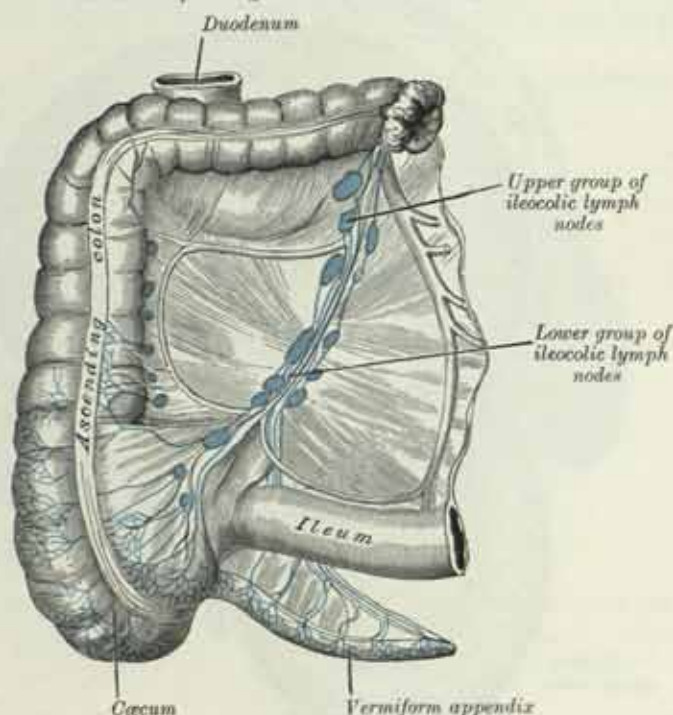
(d) *The lymphatic drainage of the spleen.*—The collecting vessels from the capsule of the spleen end in the pancreaticosplenic lymph nodes.

2. *The superior and inferior mesenteric lymph nodes and their area of drainage.*—The superior and inferior mesenteric lymph nodes lie on the front of the abdominal aorta close to the points of origin of the arteries of the same

names. They are the terminal groups for the alimentary canal from the duodeno-jejunal flexure to the upper part of the rectum, and receive afferents from the outlying groups which lie along the jejunal, ileal, colic and superior rectal arteries.

(a) *The lymphatic drainage of the jejunum and ileum.*—The lacteals pass between the layers of the mesentery, but, before reaching the superior mesenteric lymph nodes, the lymph passes through the **lymph nodes of the mesentery**. These vary from one hundred to one hundred and fifty in number and comprise three sets, viz.—one lying close to the wall of the intestine amongst the terminal twigs of the jejunal and ileal arteries; a second, in relation to the loops and primary branches of the same vessels; and a third, along the upper part of the trunk of the superior mesenteric artery. The lymph from the terminal few inches of the ileum follows the ileal branch of the ileocolic artery to end in the ileocolic lymph nodes.

FIG. 793.—The lymph vessels and nodes of the cæcum and vermiform appendix. Anterior aspect. (Jamieson and Dobson.)



Applied Anatomy.—Enlargement of the mesenteric lymph nodes is seen in most diseased conditions of the intestinal tract, and is well marked in enteric fever, tuberculous ulceration or malignant growths of the bowel. The enlarged lymph nodes can often be palpated through the wall of the abdomen.

(b) *The lymphatic drainage of the colon.*—The lymph from the colon drains into both the superior and the inferior mesenteric lymph nodes, in accordance with the arterial supply of this part of the gut. Outlying groups of lymph nodes, which are placed along the course of the colic, ileocolic and superior rectal arteries, are interposed on the pathway of the colic lymph vessels.

The **lymph nodes of the colon** are divided into four groups: (a) epicolic, (b) paracolic, (c) intermediate colic and (d) terminal colic.

The *epicolic lymph nodes* are merely minute nodules situated on the wall of the gut, sometimes in the appendices epiploicæ. The *paracolic lymph nodes* lie along the medial borders of the ascending and descending colon, and along the mesenteric borders of the transverse and sigmoid colon. The *intermediate colic lymph nodes* lie along the right, middle and left colic arteries. The *terminal colic lymph nodes* are placed on the main trunks of the superior and inferior mesenteric arteries, and are in direct continuity with the corresponding pre-aortic lymph nodes.

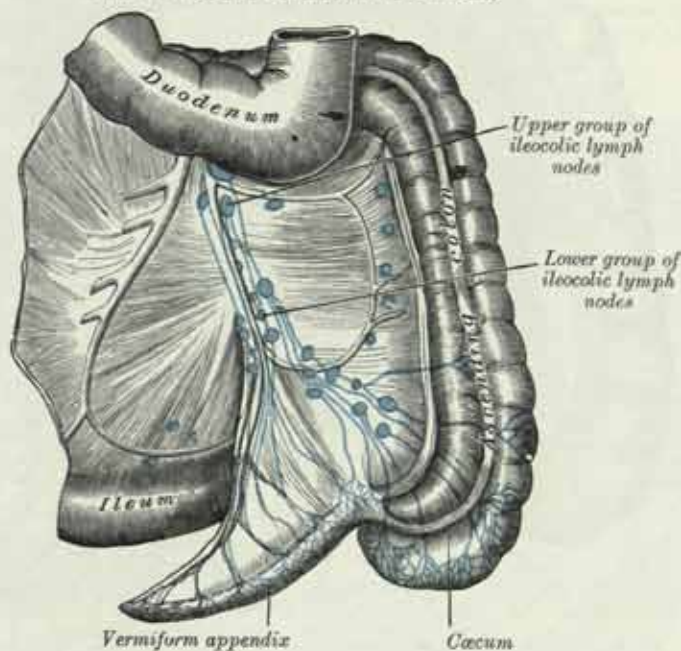
The **pararectal lymph nodes** lie in contact with the muscular coat of the

rectum. Their efferents pass to an intermediate group around the superior rectal artery and thence to the lymph nodes at the origin of the inferior mesenteric artery. Others pass to the lymph nodes at the bifurcation of the common iliac artery.

The **ileocolic lymph nodes** (figs. 793, 794), from ten to twenty in number, form a chain around the ileocolic artery, but show a tendency to subdivision into two groups, one near the duodenum and another on the lower part of the trunk of the artery. Where the vessel divides into its terminal branches the chain is broken up into several groups, viz.: (a) *ileal*, in relation to the ileal branch of the artery; (b) *anterior ileocolic*, usually three in number, in the ileocaecal fold, near the wall of the caecum; (c) *posterior ileocolic*, mostly placed in the angle between the ileum and the colon, but partly lying behind the caecum at its junction with the ascending colon; (d) a single lymph node in the mesentery of the vermiform appendix.

The *lymph vessels of the vermiform appendix and caecum* (figs. 793, 794) are numerous, since there is a large amount of lymphoid tissue in the walls of these parts

FIG. 794.—The lymph vessels and nodes of the caecum and vermiform appendix. Posterior aspect. (Jamieson and Dobson.)



of the digestive tube. From the body and tip of the vermiform appendix eight to fifteen vessels ascend between the layers of its mesentery, one or two being interrupted in the lymph nodes which lies in this peritoneal fold. They unite to form three or four vessels, which end partly in the lower and partly in the upper lymph nodes of the ileocolic chain. The vessels from the root of the vermiform appendix and from the caecum comprise an anterior and a posterior group. The anterior vessels pass in front of the caecum, and end in the anterior ileocolic lymph nodes and in the upper and lower lymph nodes of the ileocolic chain; the posterior vessels ascend over the back of the caecum and terminate in the posterior ileocolic lymph nodes and in the lower lymph nodes of the ileocolic chain.

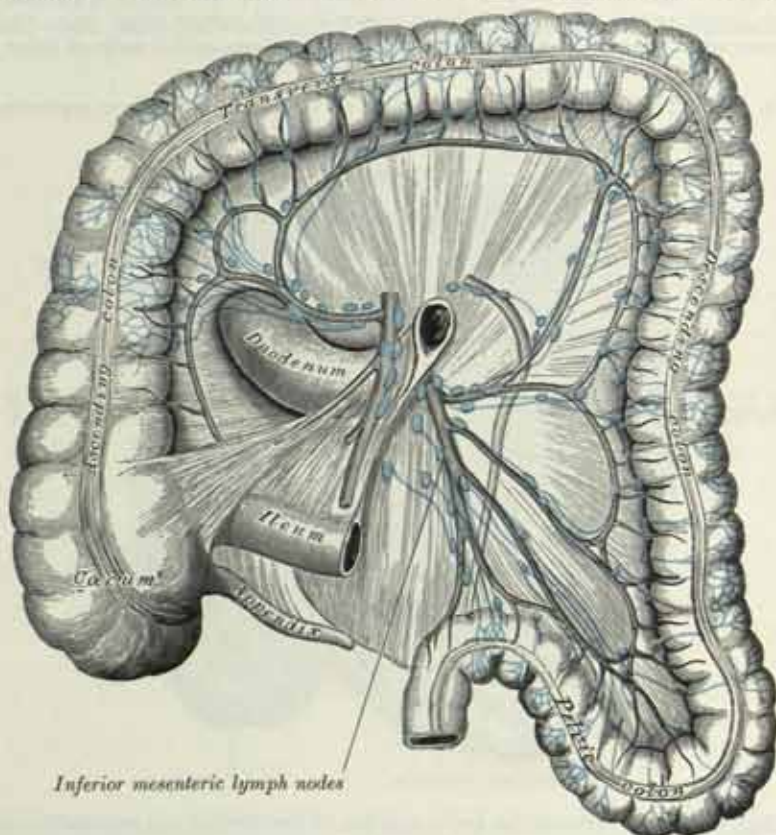
Lymph vessels of the colon (fig. 795).—The lymph vessels of the ascending and transverse parts of the colon end in the superior mesenteric lymph nodes, after traversing the right colic and middle colic lymph nodes. Those of the descending and sigmoid parts of the colon are interrupted by the small lymph nodes on the branches of the left colic arteries, and ultimately end in the pre-aortic lymph nodes around the origin of the inferior mesenteric artery.

(c) *The lymphatic drainage of the rectum and anal canal*.—From the upper half, or more, of the rectum the lymph vessels pierce the wall of the gut and ascend along the superior rectal vessels, through the pararectal lymph nodes to reach the nodes in

the lower part of the sigmoid mesocolon and those associated with the inferior mesenteric artery. From the lower half, and from the anal canal *above the mucocutaneous junction* the lymph flow passes upwards to pierce the wall of the gut and accompany the middle rectal vessels to the internal iliac lymph nodes. Some of these are said to pierce the insertion of the levator ani muscle and to gain the ischio-rectal fossa and there they accompany the inferior rectal and internal pudendal vessels and so reach the internal iliac nodes.

The lymph vessels of the anal canal *below the mucocutaneous junction* descend to the anal margin and then pass laterally to reach the most medial of the superficial inguinal lymph nodes.

FIG. 795.—The lymph vessels and nodes of the colon. (Jamieson and Dobson.)



B. THE LATERAL AORTIC LYMPH NODES AND THEIR AREA OF DRAINAGE (fig. 796)

The **lateral aortic lymph nodes** lie on each side of the abdominal aorta in front of the medial margin of the Psoas major, the crus of the Diaphragm and the sympathetic trunk. On the right side some members of the group lie to the lateral side of the inferior vena cava and in front of the vessel near the termination of the right renal vein. Afferents reach the lateral aortic lymph nodes from the structures supplied by the lateral and dorsal branches of the aorta and from the outlying lymph nodes associated with the iliac arteries and their branches. Efferents from the lateral aortic lymph nodes on each side form the *lumbar trunk*, and the right and left lumbar trunks terminate in the cisterna chyli. A few efferents may pass to the pre-aortic and retro-aortic groups.

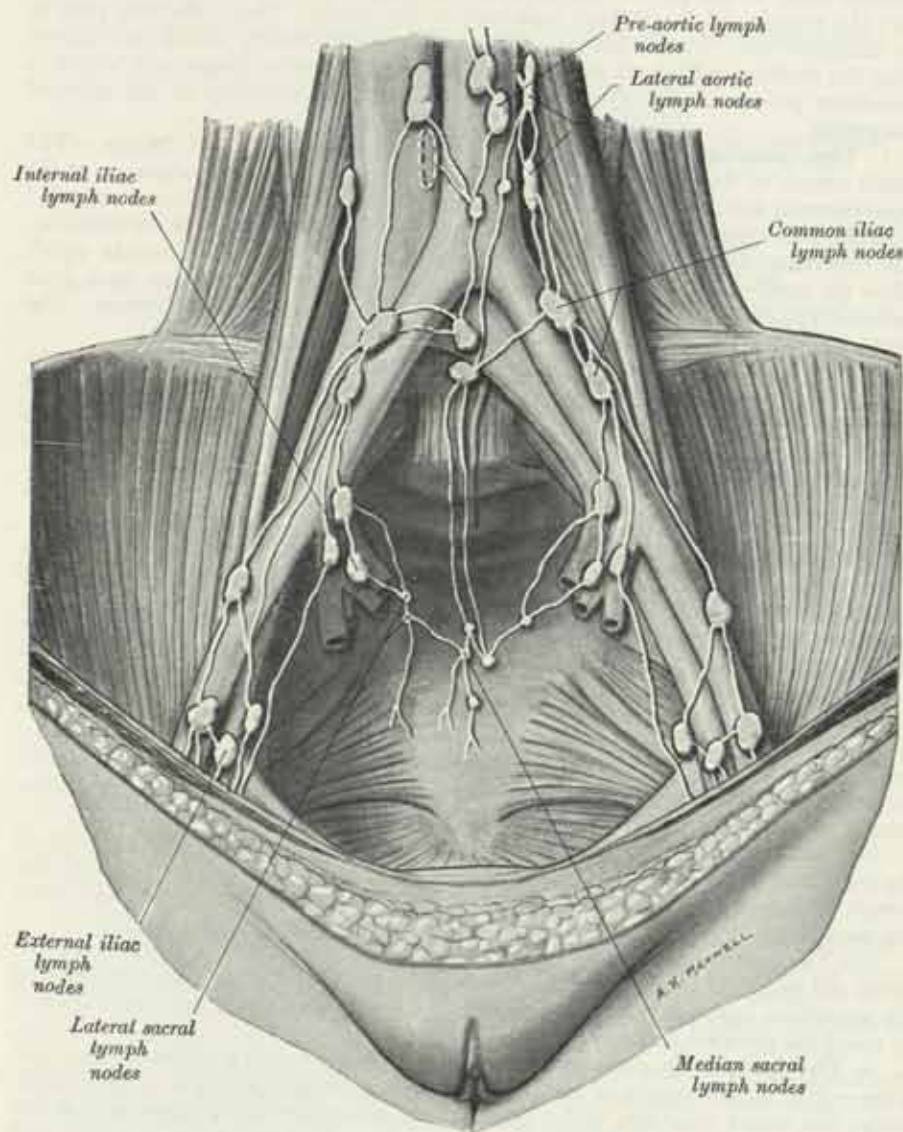
The lymph vessels from the kidney and the abdominal portion of the ureter, from the posterior abdominal wall, from the testis in the male, and from the ovary, the uterine tube and the upper part of the uterus in the female all pass directly to the lateral aortic lymph nodes without being interrupted in any intermediate

group. The lymph vessels from the pelvis and most of the pelvic viscera and from the lateral and anterior parts of the abdominal wall pass first through outlying groups which are associated for the most part with the iliac arteries and some of their branches. They include the following groups:

Common iliac.
External iliac.
Internal iliac.

Inferior epigastric.
Circumflex iliac.
Sacral.

FIG. 796.—The lymph nodes of the pelvis. Semi-diagrammatic.



The *common iliac lymph nodes*, four to six in number, are grouped behind and on the sides of the common iliac artery, one or two being placed below the bifurcation of the aorta in front of the fifth lumbar vertebra or the promontory of the sacrum. They receive afferents from the external and internal iliac lymph nodes, and send their efferents to the lateral aortic group.

The *external iliac lymph nodes*, about eight to ten in number, lie along the external iliac vessels. They are usually in three groups, one on the lateral side, another on the medial side, and a third in front of the vessels, but the last-named

group is inconstant. They receive afferents from the inguinal lymph nodes (p. 896), from the deeper layers of the infra-umbilical part of the abdominal wall, from the deep part of the adductor region of the thigh, from the glans penis vel clitoridis, the membranous urethra, the prostate, the fundus of the urinary bladder, the cervix uteri and part of the vagina. Their efferents pass to the common iliac lymph nodes. The *inferior epigastric* and the *circumflex iliac lymph nodes*, which are associated with the vessels of the same names and drain the corresponding areas, are outlying members of the external iliac group. They are inconstant in number.

The *internal iliac lymph nodes* surround the internal iliac vessels. They receive afferents from all the pelvic viscera, from the deeper parts of the perineum, and from the muscles of the buttock and back of the thigh. Their efferents pass to the common iliac lymph nodes. The *sacral lymph nodes*, which are placed along the median and lateral sacral vessels, and the *obturator lymph node*, which is sometimes present in the obturator canal, are outlying members of the internal iliac group.

1. **The lymphatic drainage of the urinary tract.**—(a) *The kidney.*—The lymph vessels of the kidney begin in three plexuses: one in the substance of the organ between and around the renal tubules; a second beneath the fibrous capsule; and a third which communicates freely with the subcapsular plexus, in the renal fat. The collecting vessels from the intrarenal plexus form four or five trunks which follow the renal vein and end in the lateral aortic lymph nodes; as they issue from the hilus they are joined by the collecting vessels from the subcapsular plexus. The plexus in the renal fat drains directly into the lateral aortic lymph nodes.

(b) *The ureter.*—The lymph vessels of the ureter begin in submucous, intramuscular and adventitial plexuses which communicate with each other. The collecting vessels from the upper part of the ureter may join the renal collecting vessels or may pass directly to the lateral aortic lymph nodes near the origin of the testicular (or ovarian) artery; those from the succeeding part pass to the common iliac lymph nodes; and those from the pelvic part of the ureter may end in the common, the external or the internal iliac lymph nodes.

(c) *The bladder.*—The lymph vessels of the bladder (fig. 797) take origin in three plexuses—a submucous,* an intramuscular and an extramuscular. The collecting vessels, nearly all of which end in the external iliac lymph nodes, are arranged in three sets: the vessels from the region of the trigone emerge on the base of the bladder and run upwards and laterally; those from the superior surface converge on the posterolateral angle and then pass upwards and laterally across the lateral umbilical ligament to reach the external iliac lymph nodes (one of the vessels of this set may go to the internal or common iliac group); those from the inferolateral surface pass towards its upper part and then run with those from the superior surface. Minute nodules of lymphoid tissue may be found along the course of the lymph vessels of the bladder.

(d) *The urethra.*—(i) The vessels from the prostatic and membranous parts in the male, and from the whole urethra in the female, pass mainly to the internal iliac lymph nodes; a few may end in the external iliac lymph nodes. The vessels from the membranous part accompany the internal pudendal artery.

(ii) The vessels of the spongy urethra in the male accompany those of the glans penis and end in the deep inguinal lymph nodes (p. 896). Some may terminate in the superficial inguinal lymph nodes, and others may pass along the inguinal canal to reach the external iliac group.

2. **The lymphatic drainage of the male reproductive organs.**—(a) *The testis.*—The lymph vessels of the testis commence in two plexuses—a superficial, under the tunica vaginalis, and a deep, in the substance of the testis and in the epididymis. Four to eight collecting trunks ascend in the spermatic cord and accompany the testicular vessels as they lie on the psoas major muscle; they end in the lateral aortic and pre-aortic lymph nodes.†

(b) *The ductus deferens, seminal vesicle and prostate.*—The collecting vessels from the ductus deferens end in the external iliac lymph nodes. Those from the seminal vesicle go to both the internal and external iliac groups.

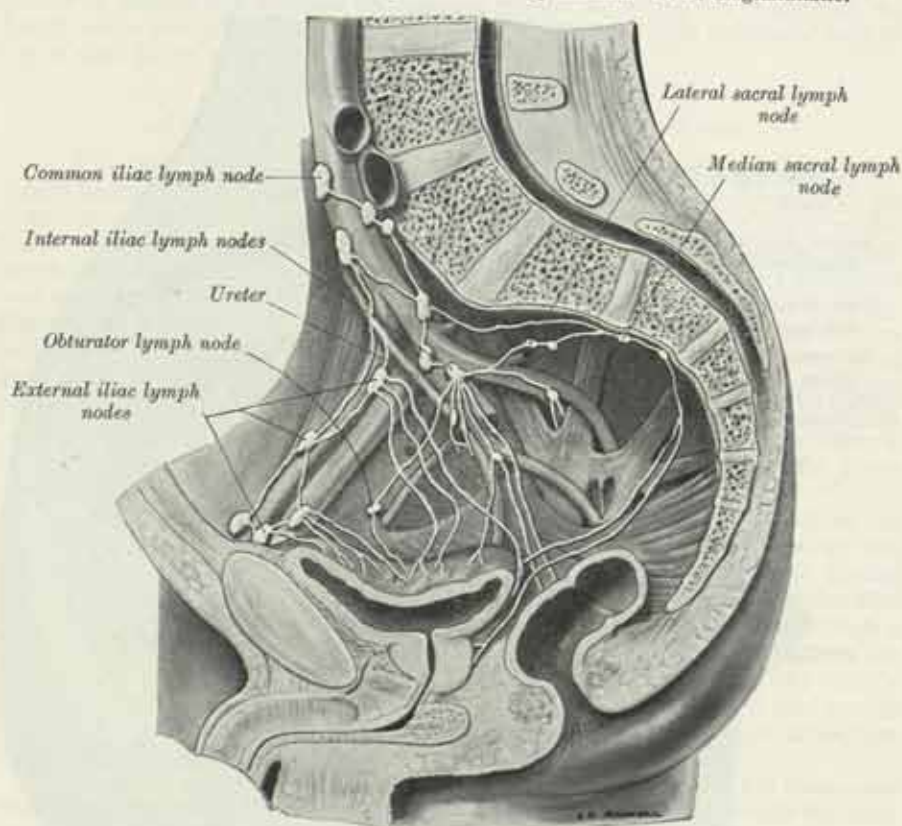
* See *Médecine opératoire des voies urinaires*, J. Albarran, Paris, 1909; and *Anatomie des lymphatiques de l'homme*, H. Rouvière, Paris, 1932.

† "The Lymphatics of the Testicle," by J. K. Jamieson and J. F. Dobson, *Lancet*, February 19th, 1900.

The prostatic lymph vessels terminate chiefly in the internal iliac and sacral lymph nodes; a trunk from the posterior surface passes with the lymph vessels of the bladder to the external iliac nodes, and another from the anterior surface gains the internal iliac group by joining the lymph vessels of the membranous urethra.

(c) *The scrotum and penis.*—The skin covering these parts is drained by vessels which, together with those of the whole of the perineal skin, pass along the course of the external pudendal blood-vessels to the superficial inguinal lymph nodes. The lymph vessels of the glans penis pass to the deep inguinal and external iliac groups.

FIG. 797.—The lymphatic drainage of the urinary bladder. Semi-diagrammatic.



3. The lymphatic drainage of the female reproductive organs (fig. 798).—

(a) *The ovary.*—The lymph vessels of the ovary, like those of the testis, ascend along the ovarian artery to the lateral aortic and pre-aortic lymph nodes.

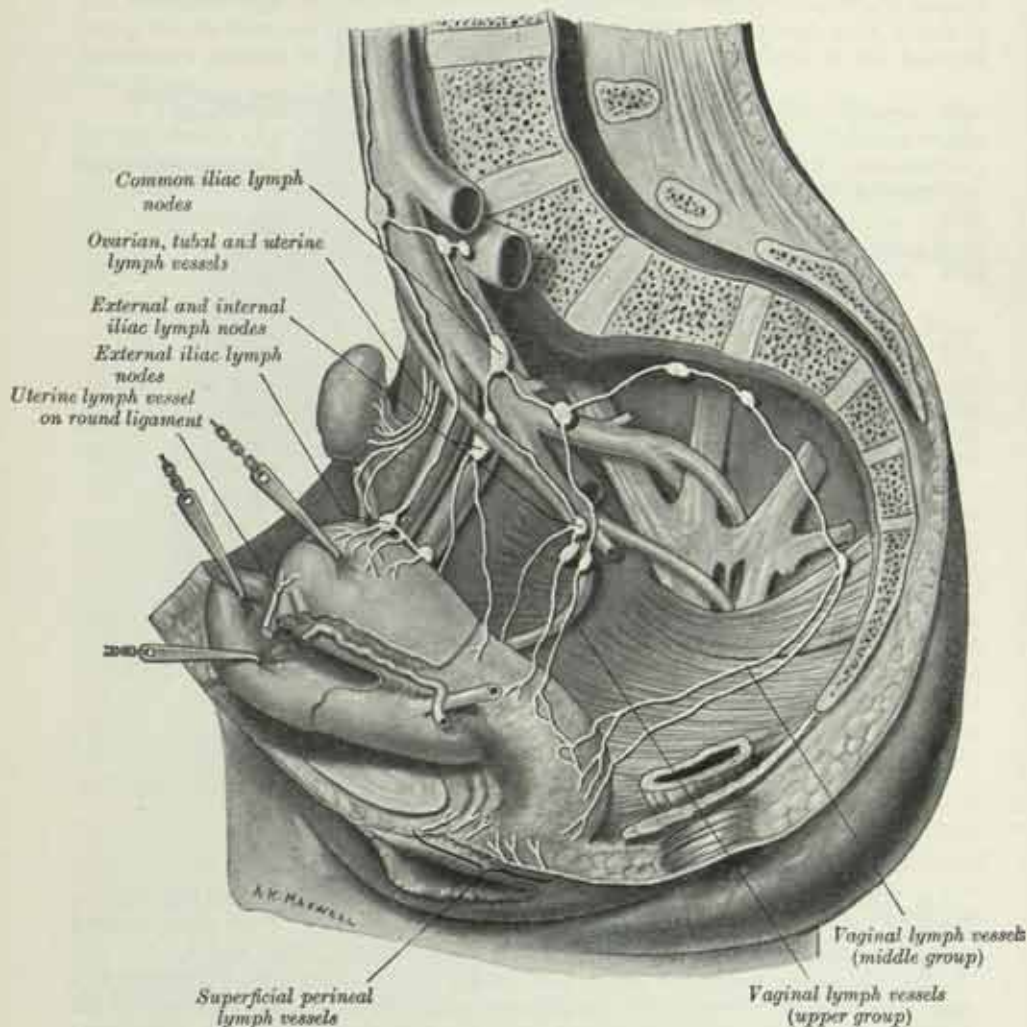
(b) *The uterus and uterine tube.*—The lymph vessels of the uterus comprise two sets: a superficial, beneath the peritoneum, and a deep, in the substance of the uterine wall. The collecting vessels from the cervix pass in three directions: laterally in the parametrium to the external iliac lymph nodes; posterolaterally to the internal iliac lymph nodes; and backwards in the sacrogenital fold to the sacral lymph nodes. The vessels from the lower part of the body pass mostly to the external iliac lymph nodes, accompanying those from the cervix. From the upper part of the body, the fundus and the uterine tube the vessels accompany those of the ovary to the lateral aortic and pre-aortic lymph nodes; a few, however, pass to the external iliac lymph nodes. The region near the point of entry of the uterine tube is drained by vessels which accompany the round ligament and so reach the superficial inguinal lymph nodes. The lymph vessels of the uterus enlarge greatly during pregnancy.

(c) *The vagina.*—The lymph vessels of the vagina anastomose with those of the cervix uteri, the rectum and the vulva. They are in three groups, but the areas

drained by the three sets are not sharply demarcated. The vessels from the upper part accompany the uterine artery to the external iliac lymph nodes. The middle part is drained by vessels which accompany the vaginal artery and end in the external iliac lymph nodes. The vessels of the vagina below the hymen, the vulva, and the skin of the perineum as a whole pass to the superficial inguinal lymph nodes.

4. **The lymphatic drainage of the abdominal wall.**—The lymph vessels of the abdominal wall are in two sets: superficial, in the superficial fascia; and deep, draining the muscles, etc.

FIG. 798.—The lymphatic drainage of the female reproductive organs. Semi-diagrammatic. (After Cunéo and Marcille.)



The *superficial lymph vessels* accompany the superficial blood-vessels. Those from the loin and buttock run with the superficial circumflex iliac vessels, and those from the skin of the anterior wall below the umbilicus with the superficial epigastric vessels. Both sets pass to the superficial inguinal lymph nodes. The part above the umbilicus is drained by vessels most of which run obliquely upwards to end in the pectoral and subscapular groups of the axillary lymph nodes; a few end in the internal thoracic lymph nodes.

The *deep lymph vessels* accompany the deep arteries. Those from the posterior abdominal wall pass directly, along the course of the lumbar arteries, to the lateral aortic and retro-aortic lymph nodes; those from the upper part of the anterior abdominal wall run with the superior epigastric vessels to reach the internal

thoracic lymph nodes; those of the lower part end in the circumflex iliac, inferior epigastric, and external iliac lymph nodes. The lymph vessels of the pelvic wall follow the internal iliac artery and its parietal branches and end in the iliac or lateral aortic lymph nodes.

THE LYMPHATIC DRAINAGE OF THE THORAX

The lymphatic drainage of the thorax may be considered under two headings (*a*) drainage of the thoracic walls, and (*b*) drainage of the thoracic contents, and it should be noted that the lymph nodes on the lymphatic pathways of the thorax cannot be divided into terminal and outlying groups, as, with a few exceptions, the lymph nodes concerned drain into the thoracic duct or the right lymphatic duct or one of their larger tributaries.

A. LYMPHATIC DRAINAGE OF THE THORACIC WALLS

1. The *superficial tissues*.—The superficial lymph vessels of the thoracic wall ramify beneath the skin and converge on the axillary lymph nodes. Those over the trapezius and latissimus dorsi run forwards and unite to form about ten or twelve trunks which end in the subscapular group. Those over the pectoral region, including the vessels from the skin covering the peripheral part of the mammary gland, run backwards, and those over the serratus anterior upwards, to the pectoral group. Others near the lateral margin of the sternum pass inwards between the rib cartilages and end in the internal thoracic lymph nodes, while the vessels of opposite sides anastomose across the front of the sternum. A few vessels from the upper part of the pectoral region ascend over the clavicle to the inferior deep cervical lymph nodes.

2. The *deeper tissues*.—The lymph vessels from the deeper tissues of the thoracic walls drain mainly into three sets of lymph nodes—the internal thoracic, the intercostal and the diaphragmatic.

(*a*) The **internal thoracic lymph nodes** are four or five in number on each side, and are placed at the anterior ends of the intercostal spaces, by the side of the internal thoracic artery.* They derive afferents from the medial part of the mammary gland, from the deeper structures of the anterior abdominal wall above the level of the umbilicus, from the upper surface of the liver through a small group of lymph nodes which lies behind the xiphoid process, and from the deeper parts of the anterior portion of the thoracic wall. Their efferents usually unite to form a single trunk; this may open directly into the junction of the internal jugular and subclavian veins, or that of the right side may join the right subclavian trunk, and that of the left the thoracic duct.

(*b*) The **intercostal lymph nodes** lie in the posterior parts of the intercostal spaces and in relation to the heads and necks of the ribs. They receive the deep lymph vessels from the postero-lateral aspect of the chest; some of these vessels are interrupted by small lateral intercostal lymph nodes. The efferents of the lymph nodes in the lower four or five spaces unite to form a trunk which descends and opens either into the cisterna chyli or into the commencement of the thoracic duct. The efferents of the lymph nodes in the upper spaces of the left side end in the thoracic duct; those of the corresponding right spaces, in the right lymphatic duct.

(*c*) The **diaphragmatic lymph nodes** lie on the thoracic surface of the diaphragm, and consist of four sets, anterior, right and left lateral and posterior.

The *anterior set* comprises (*a*) two or three small lymph nodes behind the base of the xiphoid process, which receive afferents from the convex surface of the liver, and (*b*) one or two lymph nodes on each side near the junction of the seventh rib with its cartilage, which receive lymph vessels from the front part of the Diaphragm. The efferent vessels of the anterior set pass to the internal thoracic lymph nodes.

The *lateral sets* consist of two or three lymph nodes on each side close to where the phrenic nerves enter the Diaphragm. On the right side some of the lymph nodes of this group lie within the fibrous wall of the pericardium on the front of the termination of the inferior vena cava. The afferents of this set

* E. P. Stibbe, *J. Anat.*, 52, 1917.

are derived from the middle part of the Diaphragm, those on the right side also receiving afferents from the convex surface of the liver. Their efferents pass to the posterior mediastinal lymph nodes.

The *posterior* set consists of a few lymph nodes situated on the back of the crura of the Diaphragm, and connected on the one hand with the lateral aortic lymph nodes, and on the other with the posterior mediastinal lymph nodes.

The collecting lymph vessels from the deeper tissues comprise :

(a) The lymph vessels of the muscles which lie on the ribs: most of these end in the axillary lymph nodes, but some from the Pectoralis major pass to the internal thoracic lymph nodes. (b) The intercostal lymph vessels which drain the Intercostales and parietal pleura; those from the anterior half of the thoracic wall and pleura end in the internal thoracic lymph nodes; those from the posterior half, in the intercostal lymph nodes. (c) The lymph vessels of the Diaphragm, which form two plexuses, one on its thoracic and another on its abdominal surface; these plexuses anastomose freely with each other, and are best marked on the parts covered respectively by the pleuræ and peritoneum. *The plexus on the thoracic surface* unites with the lymph vessels of the costal and mediastinal parts of the pleura, and its efferents consist of three groups: anterior, passing to the anterior diaphragmatic lymph nodes, which lie near the junction of the seventh rib with its cartilage; middle, to the lymph nodes on the œsophagus and to those around the termination of the inferior vena cava; and posterior, to the lymph nodes which surround the aorta at the point where this vessel leaves the thoracic cavity. *The plexus on the abdominal surface* is composed of fine vessels, and anastomoses with the lymph vessels of the liver and, at the periphery of the Diaphragm, with those of the subperitoneal tissue. The efferents from the right half of this plexus terminate partly in a group of lymph nodes on the trunk of the corresponding phrenic artery, while others end in the right lateral aortic lymph nodes. Those from the left half of the plexus pass to the pre-aortic and lateral aortic lymph nodes and to the lymph nodes on the terminal portion of the œsophagus.

B. LYMPHATIC DRAINAGE OF THE THORACIC CONTENTS

The lymph from the thoracic viscera traverses one or other of three sets of lymph nodes, viz. brachiocephalic, posterior mediastinal and tracheobronchial, before entering the thoracic duct, the right lymphatic duct or another lymph vessel which itself enters one of the great veins at the root of the neck.

The **brachiocephalic lymph nodes** are placed in the anterior part of the superior mediastinum, in front of the brachiocephalic veins and the large arterial trunks which arise from the aortic arch. They receive afferents from the thymus and pericardium, and from the lateral diaphragmatic lymph nodes; their efferents unite with those of the tracheobronchial lymph nodes, to form the right and left bronchomediastinal trunks.

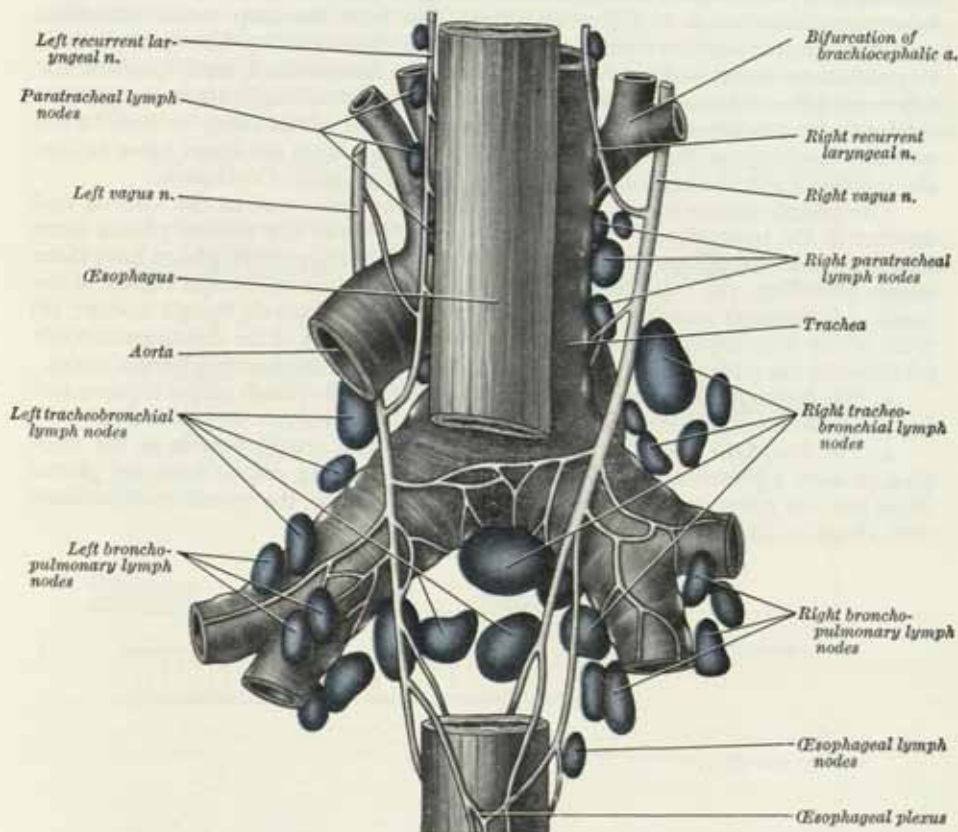
The **posterior mediastinal lymph nodes** lie behind the pericardium in relation to the œsophagus and descending thoracic aorta. Their afferents are derived from the œsophagus, the posterior part of the pericardium, the Diaphragm, and, occasionally, the left lobe of the liver. Their efferents mostly end in the thoracic duct, but some join the tracheobronchial lymph nodes.

The **tracheobronchial lymph nodes** (fig. 799) form five main groups, and include some of the largest lymph nodes in the body: (a) *paratracheal*, at the sides of the thoracic part of the trachea; (b) *superior tracheobronchial*, in the angles between the lower part of the trachea and bronchi; (c) *inferior tracheobronchial* in the angle between the two bronchi; (d) *bronchopulmonary*, in the hilus of each lung; and (e) *pulmonary*, in the lung substance, on the larger branches of the principal bronchi. These groups are not sharply demarcated from one another. The pulmonary lymph nodes become continuous at the hilus of the lung with the bronchopulmonary lymph nodes, and they in turn are continuous with the inferior and superior tracheobronchial lymph nodes, while the latter are continuous with the paratracheal group. The afferents of the tracheobronchial lymph nodes drain the lungs and bronchi, the thoracic part of the trachea, and the heart; some of the efferents of the posterior mediastinal lymph nodes also end in this group. Their efferent vessels ascend upon the trachea and unite with efferents of the internal thoracic and brachiocephalic lymph nodes to form the *right and left bronchomediastinal*

tinal trunks. The right bronchomediastinal trunk may join the right lymphatic duct, and the left the thoracic duct, but more frequently they open independently of these ducts into the junction of the internal jugular and subclavian veins of their own side.

Applied Anatomy.—In all town-dwellers there are continually being swept into these lymph nodes from the bronchi and alveoli large quantities of the dust and black carbonaceous pigment that are so freely inhaled in cities. In primary tuberculosis of the lungs these lymph nodes are practically always infected; they enlarge, being filled with tuberculous deposits that may soften, or become fibrous, or calcify. Not infrequently an enlarged tuberculous lymph node perforates into a bronchus, discharging its contents into the tube. When this happens there is great danger of acute pulmonary tuberculosis, the infecting nodal-substance being rapidly spread throughout the bronchial system by the coughing induced by its presence in the air-passages.

FIG. 799.—The lymph nodes of the trachea, bronchi and lungs.
(After Hallé.)



1. *The lymphatic drainage of the heart.*—The lymph vessels of the heart consist of two plexuses: (a) deep, immediately under the endocardium, and (b) superficial, subjacent to the visceral pericardium. The deep plexus opens into the superficial, the efferents of which form left and right collecting trunks. The *left* trunks, two or three in number, ascend in the anterior interventricular groove, receiving, in their course, vessels from both ventricles. On reaching the atrioventricular sulcus they are joined by a large trunk from the diaphragmatic surface of the heart, and then unite to form a single vessel, which ascends between the pulmonary trunks and the left atrium, and ends, usually, in one of the inferior tracheobronchial lymph nodes. The *right* trunk receives its afferents from the right atrium and from the right border and diaphragmatic surface of the right ventricle. It runs upwards in the coronary sulcus, close to the right coronary artery, and then ascends in front of the ascending aorta to terminate in one of the brachiocephalic lymph nodes, usually to the left of the median plane.

2. *The lymphatic drainage of the lungs and pleurae.*—The lymph vessels of the lungs originate in two plexuses, a superficial and a deep. The superficial plexus is placed beneath the pulmonary pleura; the deep accompanies the branches of the pulmonary vessels and the ramifications of the bronchi. In the case of the larger bronchi the deep plexus consists of two networks—a submucous, beneath the mucous membrane, and a peribronchial, outside the walls of the bronchi. In the smaller bronchi there is but a single plexus, which extends as far as the bronchioles, but fails to reach the alveoli, in the walls of which there are no traces of lymph vessels. The superficial efferents turn round the borders of the lungs and the margins of their fissures, and converge to end in the bronchopulmonary lymph nodes; the deep efferents are conducted to the hilus along the pulmonary vessels and bronchi, and end, for the most part, in the bronchopulmonary lymph nodes. No free anastomosis occurs between the superficial and deep lymph vessels of the lungs, except in the region of the hilus. In the peripheral parts of the lung small connecting channels do exist between the superficial and the deep lymph vessels and, although they are difficult to demonstrate in injected specimens, they are capable of becoming dilated so as to direct the lymph flow from the deep to the superficial vessels, when the outflow from the deep vessels is obstructed by disease of the lung or pulmonary lymph nodes. At the bottom of the fissures the lymph vessels of the adjoining lobes communicate with one another, so that although there is a general tendency for the lymph vessels from the upper lobes of the lungs to pass to the superior tracheobronchial lymph nodes and for those from the lower lobes to join the inferior tracheobronchial group, these connexions are not exclusive.

The lymph vessels of the pleura consist of two sets—one in the visceral and another in the parietal part of the membrane. Those of the visceral pleura drain into the superficial efferents of the lung, while those of the parietal pleura have three modes of ending, viz.: (a) those of the costal portion join the lymph vessels of the internal intercostal muscles and so reach the internal thoracic lymph nodes; (b) those of the diaphragmatic part are drained by the efferents of the diaphragm; while (c) those of the mediastinal portion end in the posterior mediastinal lymph nodes.

3. *The lymphatic drainage of the thymus.*—The lymph vessels of the thymus end in the brachiocephalic, tracheobronchial, and internal thoracic lymph nodes.

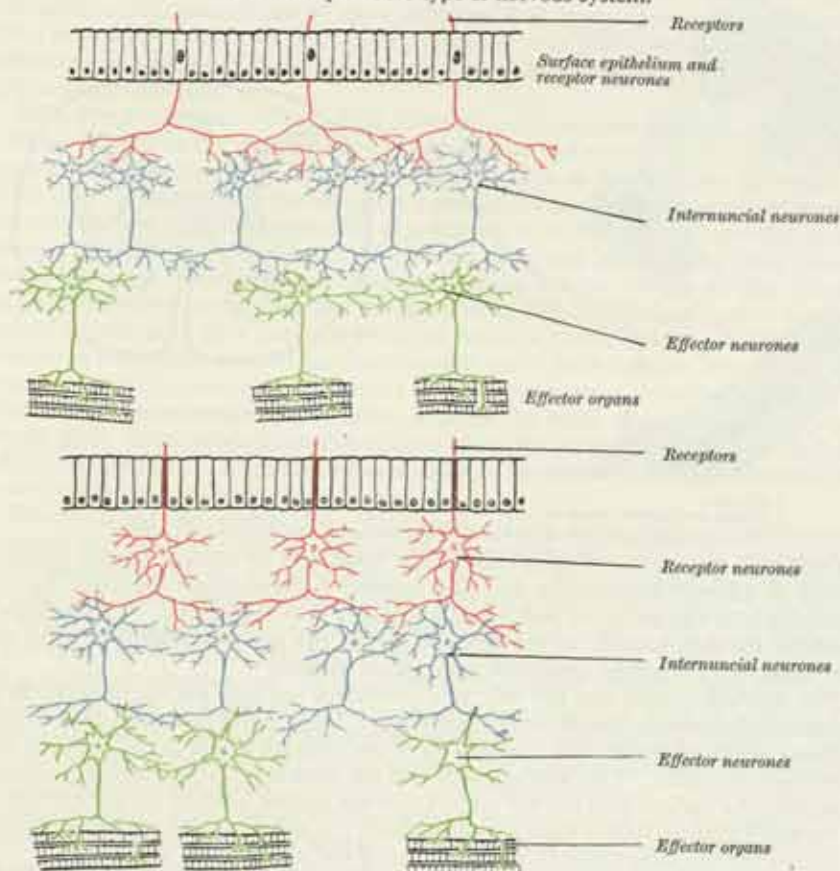
4. *The lymphatic drainage of the œsophagus.*—The lymph vessels of the œsophagus form a plexus round that tube, and the collecting vessels from the plexus drain into the posterior mediastinal lymph nodes. Below, the vessels communicate with those on the lesser curvature of the stomach.

NEUROLOGY

INTRODUCTORY

EXCITABILITY and conductivity are two of the fundamental properties of living protoplasm which enable an organism to respond to changes or events in its environment. These changes or events which excite an organism are termed *stimuli* whilst the resultant effects are termed *responses* or *reactions*. In unicellular and simple organisms such as the amoeba the reception of the stimulus, the conduction of the resulting disturbance or *impulse* and the response are all carried out by the one mass of apparently undifferentiated protoplasm. In multicellular organs, however, there is a morphological and functional differentiation of cells and groups of cells. Specialised *receptors* are differentiated at the surface of the body for the receipt of the stimulus and specialised *effectors*, either muscle or secretory cells, are differentiated for the response. The communication between the receptors

FIG. 800.—Diagrammatic representation of two stages in the evolution of the most primitive type of nervous system.

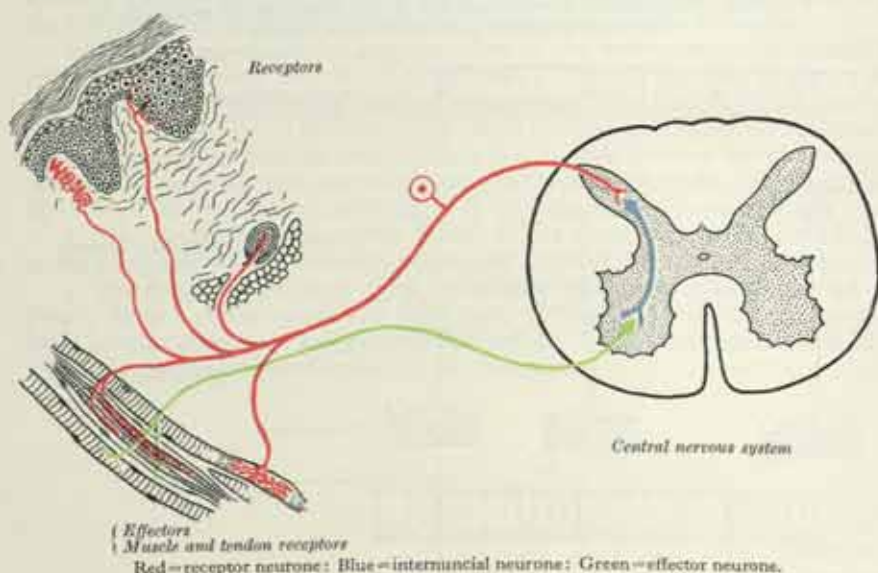


and effectors is attained either slowly through the circulatory system by the agency of chemical activators or hormones or rapidly by conducting thread-like protoplasmic-processes. The cells of origin of these processes are *nerve cells* which together with their processes are termed *neurones*. The whole chain, consisting of the receptor, conductors and effector, constitutes a *reflex arc*. This in its simplest form, includes two neurones termed the *receptor* or *sensory neurone* connected with the

receptor and the *effector* or *motor neurone* connected with the effector. The connexion between these neurones is effected at a *synapse* in which there is close apposition but no protoplasmic continuity between individual neurones. In more complex reflex arcs, other neurones termed the *internuncial neurones* intervene between the receptor and effector neurones without themselves connecting directly with either the receptor or effector.

The three neurones, receptor, internuncial and effector, are found in all nervous systems. In lower forms they display a diffuse arrangement, but with increasing complexity certain parts become localised near or in the median plane and constitute the *central nervous system*. In the higher vertebrates the cells of the receptor neurones, except those in the olfactory epithelium, are collected in ganglia and with one possible exception (p. 991) remain outside the central nervous system. They are connected with receptor end-organs, situated at the surface and within the body, by means of peripherally directed processes, the dendrites (see p. 38), and with the central nervous system by centrally directed processes, the axons, which enter the central nervous system in the *sensory* or *afferent roots* of the peripheral nerves. The internuncial neurones and the cell bodies and dendrites of the effector neurones are incorporated in the central nervous system whilst the axons of the efferent neurones leave the central nervous system in the *motor* or *efferent roots* of the peripheral nerves (fig. 800 A and B and fig. 801).

Fig. 801.—Diagrammatic representation of the neurones in a reflex arc.



Owing to the mode of progression, the head end is subject to the greatest number of afferent impressions and this number is enormously increased by the development of the olfactory and visual apparatus in this situation. These factors determine the enlargement of the cephalic end of the nervous system to form the *brain* whilst the remainder constitutes the *spinal medulla*.

The nervous system acts not only as a conductor but also for the integration of impulses and the co-ordination of the responses. These latter functions are possible by virtue of the synapses and multiplicity of connexions which occur between the constituent neurones. This arrangement and the presence of internuncial neurones connecting the various parts of the central nervous system permits the interaction of the various impulses which impinge on the body; it also provides one of the principal means for the integration of the activities of the organism as a whole.

Under normal circumstances the impulses are conducted towards the cell body in dendrites and away from it in axons, but the dendrites of many sensory cells, because of their length, are often incorrectly termed axons.

THE STRUCTURAL COMPONENTS OF THE NERVOUS SYSTEM

The general features of nervous tissue have been considered on pages 37 to 44, and it will suffice here to summarise the main points. Nerve-cells differ from other

cells in being highly specialised, in having no centrosome (they have lost the power of reproduction) and in exhibiting Nissl's bodies and neurofibrils in the cytoplasm. They occur as three main types, namely, bipolar, unipolar and multipolar nerve-cells which differ from one another in their shape and in the number and arrangement of their processes (p. 39). Receptor neurones possess bipolar or unipolar nerve-cells; the nerve-cells of internuncial and effector neurones are multipolar. Within the central nervous system nerve-fibres are devoid of neurolemmal sheaths and therefore cannot regenerate (p. 43) after they have been severed.

Receptor neurones.—The nerve cells of the retina, the olfactory mucous membrane and the eighth cranial nerve ganglia are bipolar; all other receptor neurones possess unipolar cells. Both bipolar and unipolar neurones have two processes, peripheral and central. In bipolar neurones the processes are connected to opposite poles of the cell; in unipolar neurones they arise from the cell by a common trunk which makes a T-shaped bifurcation soon after its origin. The peripheral process conveys a nerve impulse from the appropriate nerve-ending in the tissues to the nerve-cell situated—except in the case of the visual and olfactory receptors—in the sensory ganglion of the nerve concerned. The central process conveys the impulse from the cell to the central nervous system via the sensory root of the nerve. Before entering the central nervous system, these processes, which constitute the *afferent* or *sensory nerve-fibres*, are all provided with a neurolemmal sheath; they may or may not be myelinated. When the central processes traversing the sensory roots of the nerves enter the brain or spinal medulla they lose their neurolemmal sheath (p. 43). After entering the central nervous system the central processes usually give off one or more collateral branches; these and the terminals of the fibre itself form junctions, termed *synapses*, with internuncial neurones. The nature of the synapse (p. 916) and the types of peripheral receptor endings (p. 919) will be discussed later.

Effector neurones.—The cells of effector neurones are multipolar. Collections of these cells form the motor nuclei of the cranial and spinal nerves. Their dendrites and cell bodies form synapses with the axons in internuncial neurones, by which they are linked with the receptors entering the nervous system via the sensory nerve-roots* or with internuncials in other parts of the central nervous system through fibre tracts. The *axons* of effector neurones leave the central nervous system by the motor roots of the cranial and spinal nerves. While within the central nervous system they possess a myelin sheath, but they do not acquire a neurolemmal sheath until they pass out from the brain or spinal medulla. The effector neurone is frequently termed the *final common motor path* because it is the channel through which the nerve impulse passes to the effector organ, whether coming from internuncials completing simple reflex arcs in the same segment or from more remote parts of the central nervous system along the great fibre tracts of the brain and spinal medulla. The mode of termination of the axons of effector neurones will be described later (p. 926).

Internuncial or connector neurones.—The nerve-cells of internuncial neurones like those of the effector neurones are multipolar. With the exception of those associated with the autonomic system (p. 1197) these cells and their processes are confined to the central nervous system. The dendrites are comparatively short, and branch repeatedly and irregularly close to the cell-body. The axon is usually longer than the dendrites and may extend as much as 100 cm. before it breaks up into a terminal arborisation. It also gives off branches, termed *collaterals*, one of which arises near its origin from the nerve-cell, but comes off at right angles to the course of the axon and is easily distinguished from the branches of a dendrite. Since they do not leave the central nervous system, the axons of internuncial neurones, although usually medullated, are devoid of a neurolemmal sheath. The internuncial neurones transmit nerve impulses from receptor neurones to effector neurones. The link may be a simple one as, for example, in many of the spinal reflex arcs confined to one segment of the spinal medulla, where the incoming receptor is linked to the outgoing effector by a single, short, internuncial neurone. On the other hand, a number of internuncials may be interposed between the receptor and the effector neurones. Of these some may carry impulses to higher centres, where they form synapses with others in a complicated series which eventually links up with

* In a few cases the receptor neurones may form synapses *directly* with the effector neurone without the interposition of a connector neurone.

effector neurones. The majority of the ascending and descending fibre tracts of the brain and spinal medulla are formed by the axons of these internuncial neurones.

The Synapse.—Communications between individual neurones are established by means of synapses, which never imply continuity of structure. The terminals of the collaterals (p. 915) and of the subdivisions of the axons end in small swellings, termed *boutons terminaux* or 'end-feet', which are closely applied to the dendrites and cell bodies of other neurones. They may take the form of small bulbs, loops or rings, and they are the first part of the axon to undergo degenerative changes when it is severed and loses continuity with its parent cell. The cell bodies and dendrites of all neurones in the central nervous system are linked with other neurones by means of synapses; in the case of the effector cells in the anterior grey column of the spinal medulla—which constitute the 'final common motor path'—and are therefore played on by numerous different centres—the number of these may exceed a thousand (p. 936).

It is a characteristic and invariable feature of a synapse that nerve impulses can pass in only one direction. The transmissibility is irreversible and this fact has been described as 'dynamic polarity'. Stimuli are capable of passing in the reverse direction along the axon to the cell-body and the dendrites, but there is no evidence that they can pass through the synapse from the cell-body to an axon or from a dendrite to an axon.

The passage of a nervous impulse across a synapse is always accompanied by a slight delay in conduction (see p. 917) and the synapses are more susceptible to fatigue and to lack of oxygen than the axons or dendrites. Finally, many drugs, notably strychnine and nicotine, act at the synapses.

It should be observed that two features of internuncial and effector nerve-cells, (1) the profusion of their synaptic connexions and (2) the collaterals given off by their axons, facilitate the correlation and association of afferent impressions and the co-ordination of efferent impulses, which are the essential factors in mental development. By the profusion of their synaptic connexions the cells are brought into functional relationship with a large number of other cells, and by means of the collaterals given off by their axons the cells are able to discharge their impulses into a number of different channels (see also p. 1039).

The Neurone Theory.—Waldeyer's *Neurone Theory* holds that each neurone is an independent anatomical unit and that, although nervous impulses pass from one neurone to another at a synaptic junction, there is no structural continuity between them. This view has been attacked from time to time, but it still receives very general support from neurologists. Striking evidence in its favour can be obtained by observing the effects of injury or disease of the cell body. The Nissl bodies undergo *chromatolysis* and eventually disappear not only from the cell body but also from the dendrites. The neurofibrils become swollen and hypertrophied at first, and later they break up and may disappear completely, a degenerative process which the dendrites and the axon share with the cell body. These changes, however, are strictly limited to the neurone concerned and do not extend beyond synaptic junctions. Each neurone, therefore, can be regarded as an independent structural unit, but functionally neurones are interdependent on one another to a remarkable extent, and every nervous impulse passes through a series of neurones before it reaches the appropriate effector. It should be stated that section of the axon also is followed by degenerative changes, usually of a transient character, in the cell body. They include chromatolysis, fragmentation of the Golgi apparatus* and displacement of the fragments and the nucleus to the periphery of the cell. This phenomenon is known as *retrograde degeneration*. When regeneration occurs, the Nissl bodies reappear first round the nucleus, which resumes its central position.

In some situations section of nerve-fibres is followed by degeneration of the nerve-cells with which they are in synaptic relation. This phenomenon is known as *transneuronal degeneration* and it is best exemplified by the degeneration which affects the cells of the lateral geniculate body when the fibres of the optic nerve are divided. The phenomenon is by no means general and it is difficult to explain why it should occur in some situations and not in others.

THE FUNCTIONAL COMPONENTS OF THE NERVOUS SYSTEM

The nervous system contains two main functional components, a *somatic component* of afferent and efferent neurones concerned with the innervation of the skin, skeletal muscles and their tendons, joints and associated connective tissues and a *splanchnic component* of afferent and efferent neurones concerned with the innervation of the viscera, glands and blood vessels. The afferent and efferent neurones in each component are linked by internuncial neurones. The arrangement of these neurones differs slightly in the two components.

In the head region *special somatic afferent* components are developed in association with the special somatic sense organs concerned with smell, vision and hearing (see p. 132), *special visceral efferent* components in association with the striped muscles developed from the branchial arches and *special visceral afferent* components in association with the organs of taste. In all, therefore, seven functional categories of neurones, *somatic afferent*, *somatic efferent*, *splanchnic afferent*, *splanchnic efferent*, *special somatic afferent*, *special visceral efferent* and *special visceral afferent* can be recognised.

This functional subdivision is reflected in the development (see p. 126) of the neural tube and is to a large extent retained in the adult (see p. 132).

NERVOUS CONDUCTION *

A nerve impulse has much in common with an electric current and a passage of an impulse along a nerve-fibre is always accompanied by a stream of electrons along it (sometimes referred to as a wave of electronegativity), the stream being followed by a transient phase (termed the *latent period*) in which no impulse can pass. Nevertheless, a nerve impulse is not an electric current, but 'a wave of activity in the nerve, which moves rapidly along the fibre and is accompanied by a potential change. The energy for the transmission of the impulse comes from the nerve itself and not from the stimulus'.† The frequency of nerve impulses however is determined by the intensity of the stimulus. The potential value and the conduction rate of a nerve impulse are constant for a given fibre but not for all fibres, for the thicker the fibre, the more rapid the rate of conduction.

On the basis of the diameter and rate of conduction the fibres in a mixed peripheral nerve can be classified into three groups, designated A, B and C.‡ The A fibres are the largest and most rapidly conducting and consist of myelinated fibres ranging from 20 μ to 1 μ in diameter. Their conduction rates vary from 120 m. to 6 m. per sec. They include the afferent fibres concerned with the transmission of impulses associated with touch, pressure and position sensibility together with the large and some finely medullated fibres from skeletal muscles. The fibres of the B group have slower conduction rates which range from 14 to 3 m. per sec. and include autonomic fibres. The C group are non-medullated fibres with conduction rates ranging from 1.6 m. to 0.3 m. per sec. Fine fibres in all three groups are believed to be concerned in the conduction of pain impulses. Fibres of groups B and C are clearly differentiated by their rates of conduction but owing to technical difficulties the range of diameter of the fibres in the two groups is imperfectly known. There is a good correlation between the rate of conduction of the impulse and the fibre diameter in group A fibres, but in fibres of groups B and C there is reason to believe that such a close correlation does not exist.

The potential changes which accompany the passage of impulses along a mixed peripheral nerve are compound and represent the sum of the potential changes occurring in its constituent A, B and C fibres. The potential changes accompanying the transmission of an impulse along the A fibres consist of four successive waves of different amplitude and velocity termed the α , β , γ and δ waves. The rate of conduction in the α waves is around 100 m.p.sec. as compared with 40 m.p.sec. for the γ waves. The motor neurones to striated muscle all belong to the A group. These

* A detailed discussion of recent work on the subject will be found in J. F. Fulton's *Physiology of the Nervous System*, 3rd Edition, 1955, Oxford Medical Publications.

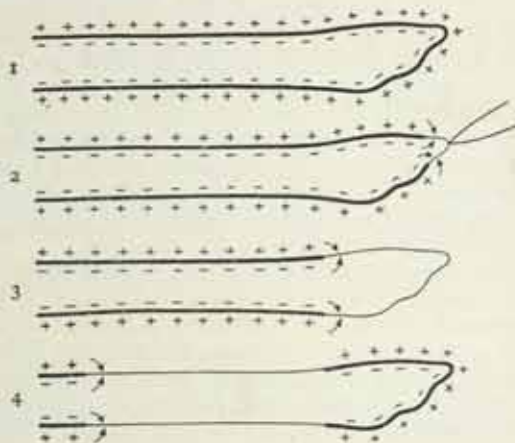
† M. A. B. Brazier, *The Electrical Activity of the Nervous System*, London, 1951.

‡ J. Erlanger and H. S. Gasser, *Electrical Signs of Nervous Activity*, Univ. Pennsylvania Press, 1937.

include large and heavily myelinated fibres which innervate ordinary striated muscle fibres, propagate waves of the α variety and fine, myelinated fibres which propagate γ waves. These fine fibres, often termed γ efferents, are believed to innervate the intrafusal fibres in the muscle spindles (see p. 925).*

The view that the passage of a nerve impulse through a neurone or series of neurones is comparable with the passage of an electric current led to the conception of what is termed the 'membrane theory' of nervous conduction. This theory postulates the presence of a film-like membrane covering the cell body and clothing all its processes. The membrane is polarised, being charged electrically with positive charges on its outer and negative charges on its inner surface (fig. 802). Wherever and however stimulated the membrane is depolarised at the point of stimulation—provided that the stimulus applied is adequate. This process spreads in all directions from end to end of the neurone concurrently with the passage of the impulse (fig. 802). Immediately following this phase of depolarisation the metabolic activities of the cell body restore the polarity of the membrane so that the normal irritability of the neurone is restored. This reparative phase provides a satisfactory explanation of the latent period which characterises every neurone following the passage of a nerve impulse.

FIG. 802.—The membrane theory of nervous conduction illustrated by diagrams of a dendrite, showing the effects of a localised stimulus on the polarised surface of the membrane of the neurone. (Reproduced from H. Chandler Elliott's *Text-book of the Nervous System*, 1947, J. B. Lippincott Co., by the courtesy of the author and the publishers.)



1. A dendritic terminal, showing the intact polarised membrane.
2. Depolarisation of membrane, initiated by local stimulus.
3. Depolarisation travelling along the dendrite.
4. Spread of depolarisation towards the cyton, followed, after a latent period, by the reconstitution of the polarised membrane.

The foregoing explanation of the factors governing the passage of a nerve impulse from one neurone to another has been challenged by the theory of humoral or chemical transmitters, for it is known that the passage of an impulse along a sympathetic postganglionic fibre is associated with the liberation of adrenalin in the region of its terminals, while the passage of an impulse along somatic efferent fibres, parasympathetic postganglionic fibres and all preganglionic fibres is associated with the liberation at their terminals of the ester, acetylcholine. According to this theory the delay at the synapse is explained by the necessity for building up the acetylcholine or adrenalin, as the case may be, to a given level before the impulse can stimulate the adjoining neurone.

The liberation of acetylcholine is associated with the presence, in or near the covering membrane, of the enzyme cholinesterase,† which has a specific action on this particular ester. The enzyme has a high concentration in all nervous tissues

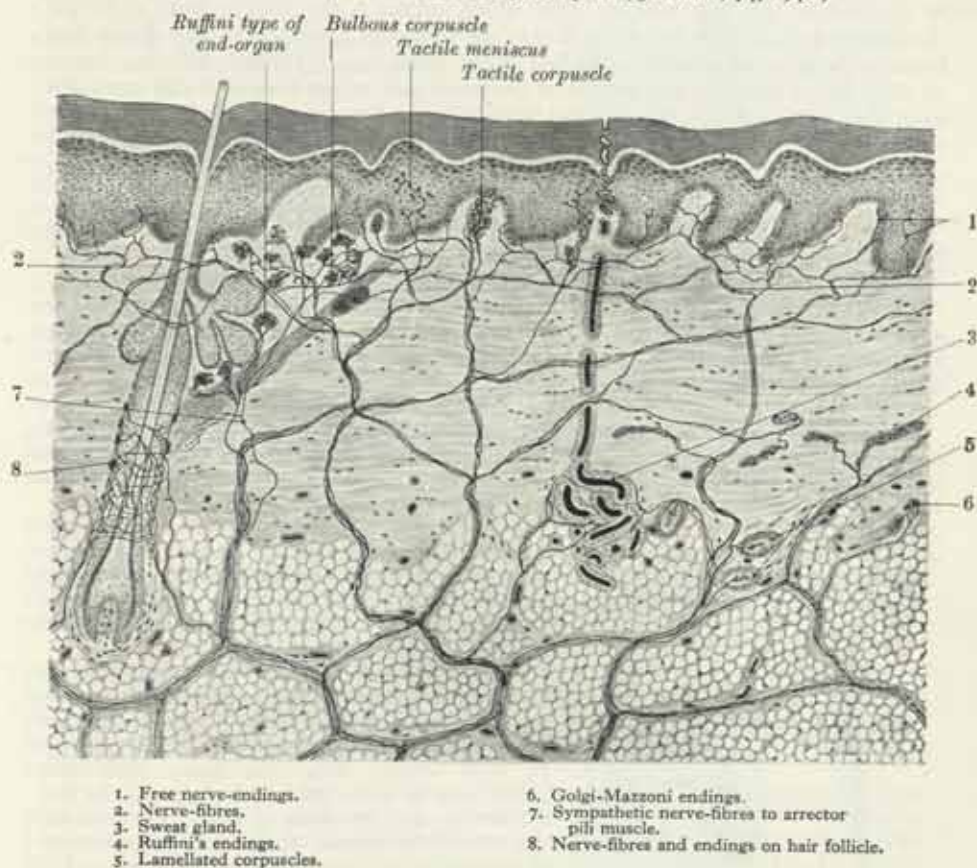
* L. Leksell, *Acta Physiol. Scand.*, 10, suppl. 21, 1945.

† D. Nachmansohn, et al., *J. biol. Chem.*, 163, 1946.

and the concentration is highest in the cell body and its synapses. In foetal lambs spinal reflexes develop at a much earlier stage than reflexes involving higher centres and it is significant that the development of these reflexes is associated with the presence of a high concentration of cholinesterase in the spinal medulla, while it is still low in the brain-stem and brain, where it does not increase until a short time before birth. Similar observations have been made in the human foetus.*

A further point of interest is the recent discovery† that during the activity of a neurone sodium ions leak into the cytoplasm from the extracellular fluid and potassium ions pass out from the neurone, the interchange indicating an alteration in the permeability of the membrane, which affects the relative ion concentrations between the inside and the outside of the membrane and may account for the electromotive force developed. However, during the recovery period metabolic changes occur within the neurone which restore its contents and membrane to the pre-stimulus state.

FIG. 803.—Composite diagram showing the innervation of the human skin.
(H. H. Woollard, G. Weddell and J. Harpman, *J. Anat.*, 74, 1940.)



TERMINATIONS OF NERVE-FIBRES

Receptor endings.—The terminations of the peripheral processes of the receptor neurones associated with general sensations (e.g. muscle sense and the senses of touch, heat, cold, pain and pressure) are widely distributed throughout the body. They can be classified according to their structure into (a) free (unencapsulated) nerve-endings, (b) nerve-endings in relation to hair, and (c) special end-organs or encapsulated nerve-endings (fig. 803).

* J. Barcroft, and D. H. Barron, *Ergebn. Physiol.*, 42, 1939 and K. A. Youngstrom, *J. Neurophysiol.*, 4, 1941.

† A. K. Hodgkin and A. F. Huxley, *J. Physiol.*, 106, 1947.

Free nerve-endings are found chiefly in the epidermis and in the epithelium covering certain mucous membranes; they are found also in the dermis, the stratified squamous epithelium of the cornea and the tympanic membrane, in the root-sheaths and papillæ of the hairs, in tendons, in periosteum, in the walls of blood-vessels, and around the bodies of the sudoriferous glands. They occur in connexion with both non-myelinated and finely myelinated nerve-fibres.

When the nerve-fibre approaches its termination in the skin, the medullary sheath suddenly disappears, leaving the axon surrounded by the neurolemma. After a time the fibre loses its neurolemma, and consists only of an axon, which can be seen, in preparations stained with gold chloride, to be made up of fine varicose fibrillæ. The fibre branches repeatedly over a relatively wide area, forming a nerve-net which interweaves with other nerve-nets derived from neighbouring fibres. Finally, each net gives origin to fine, naked terminals with bead-like extremities, placed deep to and amongst the cells of the basal, spinous and granular strata * of the epidermis.

Nerve-endings in relation to hair.*—Each hair follicle is innervated from the cutaneous plexus of nerves by myelinated fibres; their number and size is related to the size of the hair follicle. The fibres approach the follicle from different directions to reach it just below the duct of the sebaceous gland where they divide into branches which run parallel to the hair in the outer coat of the hair follicle. Some of these fibres pass into the middle of the outer coat where they give rise to naked axon filaments encircling the hair and terminating as free nerve-endings amongst the collagen bundles. Others pass into the vitreous layer between the outer and inner coats and, after losing their medullary sheaths, break up into fine filaments which terminate amongst the cells of the outer root sheath.

The **special end-organs** exhibit great variety in size and shape, but have one feature in common, viz. the terminal fibrils of the nerve are enveloped by a capsule. The bulbous, lamellated and oval corpuscles are included in this group, together with the neurotendinous and neuromuscular spindles. In addition, many other special end-organs have been described from time to time, but it is not improbable that some of these may prove to be artefacts, attributable to the special methods adopted for their demonstration.

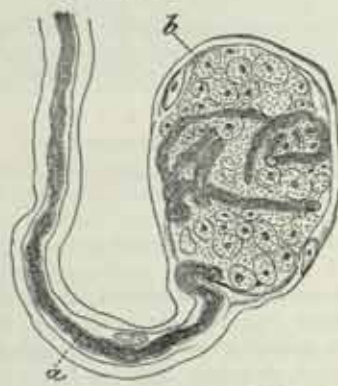
The **bulbous corpuscles** (fig. 804) are minute cylindrical or oval bodies, consisting of a capsule of connective tissue enveloping a soft semi-fluid core in which the axon terminates either in a bulbous extremity or in a coiled-up plexiform mass. End-bulbs have been found in small clusters in the papillæ and adjoining parts of the corium, in the conjunctiva (where they are spheroidal in shape in man, but cylindrical in most other animals), in the mucous membrane of the lips and tongue, and in the epineurium of nerve-trunks. Similar corpuscles

are also found in the penis and clitoris (*genital corpuscles*). It is uncertain whether they are all morphologically identical.

The **lamellated corpuscles** (Pacinian corpuscles) (fig. 805) are found in the subcutaneous tissue on the nerves of the palm of the hand and sole of the foot, and in the genital organs of both sexes; they also occur near the joints, and in some other situations, as in the mesentery and pancreas of the cat and along the tibia of the rabbit. Each of these corpuscles is attached to, and encloses the termination of, a single large nerve-fibre. The corpuscle (which is visible to the naked eye and can be most easily demonstrated in the mesentery of the cat) consists of a number of concentric lamellæ or capsules arranged around a central space, in which the nerve-fibre is contained. Each lamella is composed of bundles of fine connective tissue-fibres, and is lined on its inner surface by a single layer of flattened cells. There are fine blood vessels between the lamellæ. The central

space is elongated or cylindrical in shape, and filled with a transparent core, in the middle of which the naked axon traverses the space to the vicinity of its distal

FIG. 804.—A bulbous corpuscle. (From Klein's *Elements of Histology*.)



a. Medullated nerve-fibre. b. Capsule.

* G. Weddell, W. Pallie and E. Palmer, *Quart. J. micr. Sci.*, 95, 1954.

extremity, where it ends in one or more small knobs. Lamellated corpuscles are said to be closely associated with glomerular arteriovenous anastomoses and to derive their blood supply from these.*

Other corpuscles are found in the subcutaneous tissue of the pulp of the fingers. They differ from lamellated corpuscles in that their capsules are thinner, their contained cores thicker, and in the latter the axons ramify more extensively and end in flat expansions.

The *tactile (oval) corpuscles* (fig. 806) are elongated oval-shaped bodies which have been identified in the papillae of the corium of the hand and foot, the front of the forearm, the skin of the lips, the mucous membrane of the tip of the tongue, the palpebral conjunctiva and the skin of the nipple. They are absent from the skin of the auricle. The long axis of each corpuscle is placed at right angles to the skin or mucous surface. Each is enveloped by a connective tissue capsule of fine elastic fibres which sends membranous septa into the interior. This differentiates slowly after birth from the fibrous tissue of the corium. Superficially this capsule ends at the epidermis where it interlocks with the basal projections of the epidermal cells. In early adult life the corpuscle descends deeper into the dermis but remains anchored to the epidermis by the capsule.†

Each tactile corpuscle is supplied by a large medullated fibre, which does not branch until it has entered the capsule; it also receives an unmyelinated 'accessory' fibre which terminates in free fibrils in the capsule. The oval corpuscles occur in small groups of two or three but never singly, and ten such groups have been counted in a square mm. in the skin of the pulp of a finger in a human subject.‡

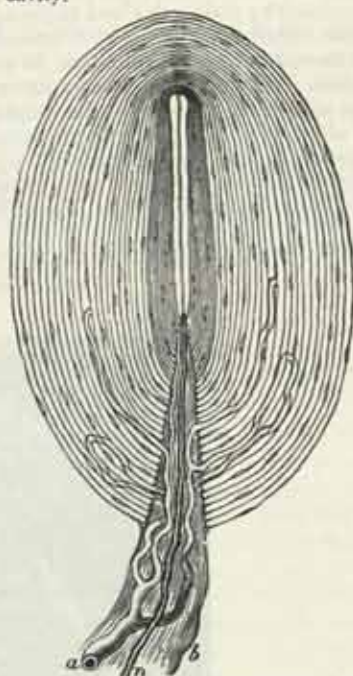
In addition, shallow cup-shaped discs, termed *tactile menisci* (of Merkel (fig. 803)), have been observed in the stratum spinosum of the skin. They are characteristic of the epidermis of the snout of the pig. Some investigators question the nature of these structures and suggest that they may be identical with the dendritic cells of the epidermis.§

Ruffini described a special variety of nerve-ending in the skin and in the subcutaneous tissue of the human finger (fig. 803), and mostly situated at the junction of the two. They are oval in shape and consist of strong connective tissue sheaths; inside these the nerve-fibres divide into numerous branches, which show varicosities and end in small free knobs. Each corpuscle receives a fine 'accessory' nerve-fibre.

The *neurotendinous endings of Golgi* are chiefly found near the junctions of tendons with muscles. Each is enclosed in a capsule which contains a number of enlarged tendon-fasciculi (*intrafusal fasciculi*). One or more nerve-fibres perforate the side of the capsule and lose their medullary sheaths; the axons subdivide and end between the tendon-fibres in irregular discs or varicosities.

The *neuromuscular spindles* (fig. 807) are present in the majority of voluntary muscles, including the extrinsic muscles of the eye and the tongue muscles.|| They have also been seen in a facial muscle in the rabbit.¶ Each neuromuscular spindle consists of a small encapsulated bundle of peculiar muscle fibres (*intrafusal fibres*), usually 2-4 in number. Each fibre consists of two polar regions separated by an equatorial region. The polar regions are cross-striated and contain widely spaced,

FIG. 805.—A lamellated corpuscle, with its system of capsules and its central cavity.



a. Arterial twig, ending in capillaries, which form loops in some of the intercapsular spaces; one penetrates to the central capsule. b. The fibrous tissue of the stalk. n. Nerve-fibre advancing to the central capsule, there losing its medullary sheath, and passing along the core to the opposite end, where it terminates in a tuberculated enlargement.

* N. Cauna and G. Mannan, *Proc. Anat. Soc. G. B. and Ireland*, 1956.

† N. Cauna and G. Mannan, loc. cit.

‡ G. Weddell, *J. Anat. Lond.*, 75, 1941.

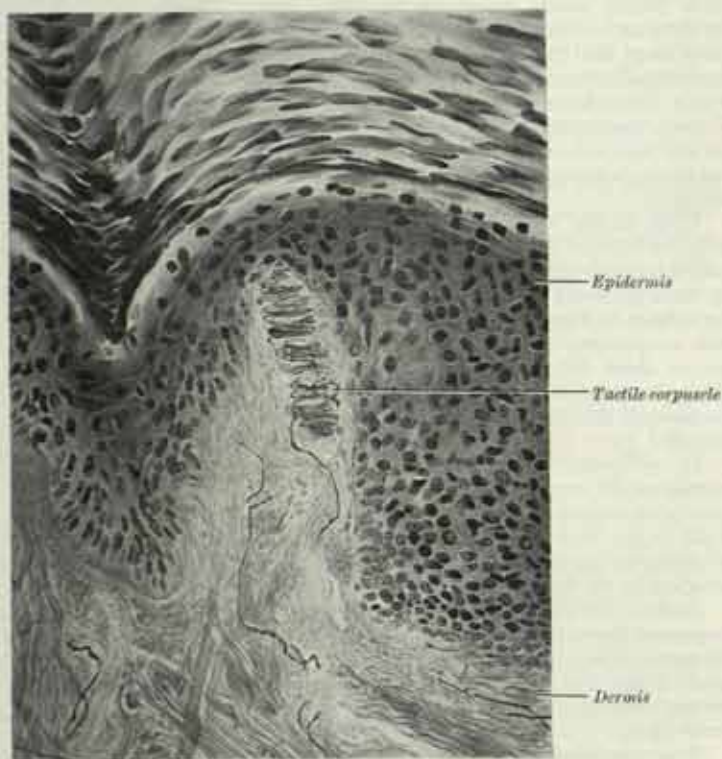
§ G. Weddell, E. Palmer and W. Pallie, *Biol. Rev.*, 30, 1955.

|| S. Cooper and P. M. Daniel, *Brain*, 72, 1949. S. Cooper, *J. Physiol.*, 122, 1953.

¶ R. E. M. Bowden and Z. Y. Mahran, *J. Anat. Lond.*, 1956.

centrally placed oval nuclei. The equatorial region displays a central fusiform swelling termed the nuclear bag, containing an aggregation of some 40-50 spherical nuclei; it is devoid of cross-striations. On either side of this is a cross-striated portion, termed the myotube region, in which the nuclei are arranged as a central chain. The nuclear bag is believed to be noncontractile and to separate the functionally independent polar regions. At the equatorial region, the capsule is lamellated with an outer connective tissue sheath separated from the axial sheaths of the muscle fibres by a space traversed by trabeculae and believed by some to contain lymph. In the polar region these sheaths merge and no lymph space separates them. The motor nerve fibres to the spindle are independent of those to the extrafusal fibres and each polar region is believed to receive an independent supply from nerve fibres of different diameter, one of which belongs to the 'alpha' group and the other to the 'gamma' group of efferent fibres. They both terminate in typical motor end plates. Each spindle receives a large medullated nerve fibre which forms a series of close spiral turns around the nuclear bag of each intrafusal fibre; it then divides into its terminals which end in flattened expansions. These terminals are known as the primary or annulospiral

FIG. 806.—Tactile corpuscle from skin of toe. Modified Bielschowsky Gros technique. $\times 250$ (From a slide lent by Dr. N. Cauna.)



endings. In addition each intrafusal fibre generally receives a second slightly smaller nerve fibre which ends in a similar manner around the myotube region in a secondary or flower spray ending.*

Functions of receptor endings.—When a receptor organ is stimulated the resulting impulse may either initiate a reflex, be transmitted to the thalamus and cerebral cortex to be appreciated in consciousness, or be transmitted to the cerebellum. The last named receives impulses arising in the proprioceptive field which do not intrude into consciousness but are important for the constant muscular readjustments which are necessary for the smooth performance of any movement.

Receptor end-organs can be classified into three main groups, *exteroceptors*, *interoceptors* and *proprioceptors*.†

* D. Barker, *Quart. J. Micr. Sci.*, 89, 1948.

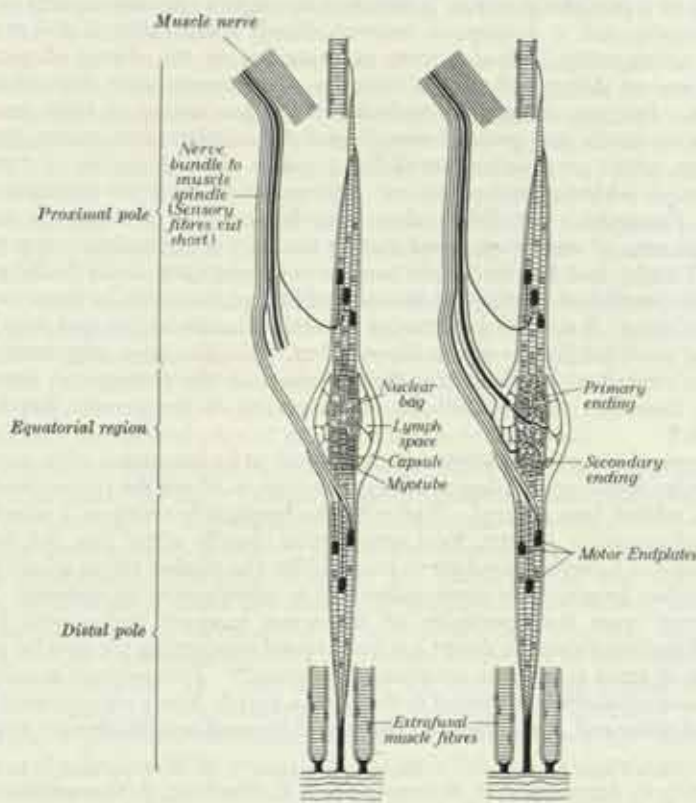
† G. S. Sherrington, *The Integrative Action of the Nervous System*, London, 1906.

Exteroceptors respond to stimuli from the external environment and are placed at or close to the surface of the body and can be subdivided into the *general* or *cutaneous sense organs* and the *special sense organs*. The general sense organs include the unencapsulated and encapsulated receptor end-organs in the skin and the receptor end-organs around hairs. The special sense organs are the olfactory, visual, auditory and taste receptors. The details concerning these may be found on pp. 1123-1294.

Interoceptors respond to stimuli arising in the viscera and are found in the walls of the digestive tract and its associated glands and in the cardiovascular system. Special receptors in the walls of blood vessels which respond to stretching of the walls by pressure from within are also included in this group. They occur in the walls of the aorta and carotid sinus and are often termed *baroreceptors*.

Proprioceptors respond to stimuli arising in the deeper tissues and especially in the locomotor system. They are concerned with movement, position and pressure and include the neurotendinous organs of Golgi, the neuromuscular spindles, the flower spray endings found in muscles and tendons and the vestibular apparatus.

FIG. 807.—Diagram of the neuromuscular spindle in a rabbit. After D. Barker. (Reproduced by permission of the Editors of the *Quart. J. Micr. Sci.*).



Exteroceptors and proprioceptors are the receptor end-organs on the somatic afferent components of the nervous system and the interoceptors constitute the receptor end-organs on the visceral afferent components.

General or cutaneous sensations.—Receptor end-organs have been generally considered to act as peripheral analysers which respond to stimuli in a specific and preferential manner,* so that each of the four modalities of cutaneous sensation,

* For details see R. Granit, *Receptors and Sensory Perception*, Yale Univ. Press, 1955.

touch, cold, warmth and heat, is subserved by a different type of end-organ. Cutaneous sensation therefore has been considered to be punctate in character, each spot overlying a single specific end-organ or a cluster of specific end-organs. Oval corpuscles (of Meissner) and the nerve endings around hair follicles are believed to respond to tactile stimuli, the bulbous corpuscles (of Krause) to cold, the Ruffini type of receptor organ to warmth and the free nerve endings in the epidermis and dermis to painful stimuli. The lamellated corpuscles (of Pacini) have been shown to be sensitive to deformation but not to thermal changes and to act as a means of transferring the stimulus to the nerve fibre thus causing its excitation.*

It should be noted, however, that in addition to their own specific nerve, many cutaneous receptor end-organs receive an 'accessory nerve fibre' from the terminal nerve network which is believed to subserve the detection of pain in the skin. These 'accessory fibres' have been considered to be associated with the sensation of pain which may result from any stimulus which is too intense.†

The discrimination and localisation of stimuli is believed, on this theory, to be based on the innervation of neighbouring receptor end-organs of similar type by different neurones and the overlapping and interweaving terminal nerve networks. The variations in the capacity to discriminate, in different regions of the body, has been related to the density of the receptor end-organs and the degree of overlap of these networks. Reduction in the density of receptor end-organs or in the degree of overlap, as after partial nerve section or during incomplete recovery following transection of a peripheral nerve, is believed to explain the impairment or loss of ability to localise and to distinguish between closely graded stimuli and to demonstrate this relationship. Head‡ from observations on the effects of sections of peripheral nerves distinguished two varieties of cutaneous pain, the *epicritic* and *protopathic*. Epicritic sensibility includes the appreciation of light touch, the localisation of tactile and painful stimuli and differentiation of minor degrees of temperature, while protopathic sensibility involves the recognition of tactile and painful stimuli without localisation and differentiation between extremes of temperature. Protopathic sensibility alone may be retained in a narrow zone surrounding an area of denervation and during recovery this sensibility returns more rapidly. Trotter and Davies§ were unable to substantiate these findings and it has not been possible to distinguish two sets of fibres to account for these two varieties of sensibility. A simpler explanation of tactile discrimination and pain localisation can be provided by the above theory || but it has also been suggested that the phenomena described by Head may be explained on the assumption that normal sensibility does not return until the interweaving of nerve-ends has been re-established.¶

Each type of receptor end-organ is considered to be associated with nerve fibres of a particular diameter and degree of myelination to which the transmission of the impulse is related (see p. 917). Nerve blocks frequently result in a selective dissociation of sensation. Thus, local anaesthetics usually affect first the fine nerve fibres which are believed to subserve pain, whilst the thicker fibres which transmit tactile impulses appear to be more vulnerable to interruption by pressure.

In recent years the specificity of cutaneous receptor end-organs has been challenged and considerable doubt has been raised concerning the precise structure and nature of some cutaneous receptor end-organs.** Temperature sensibility, for example, is adequately represented in the human auricle where no organised endings of any kind occur and, again, painful, tactile and thermal sensibilities are appreciated

* E. D. Adrian and K. Umrath, *J. Physiol.*, **68**, 1929, J. A. B. Gray and J. L. Malcolm, *Proc. Roy. Soc. B.*, **137**, 1950, J. A. B. Gray and R. B. C. Matthews, *J. Neurophysiol.*, **14**, 1951 and J. A. B. Gray and R. B. C. Matthews, *J. Physiol.*, **114**, 1951.

† The term *nociceptor* has been applied to end-organs which respond to stimuli which are harmful or noxious to the tissues. Lewis and his associates (*Brit. Med. J.*, **1**, 1938) used the term *nocifensor* for the nerves which they considered to respond in a diffuse and intense manner in the areas of hyperalgesia associated with injury. He considered these to be distinct from those nerves which respond in the ordinary way to painful stimuli.

‡ H. Head, *Studies in Neurology*, London, 1920.

§ W. Trotter and H. M. Davies, *J. Physiol.*, **38**, 1909.

|| For a critical review and references see F. M. R. Walshe, *Brain*, **65**, 1942.

¶ G. Weddell, E. Palmer and W. Pallie, *Biol. Rev.*, **30**, 1955.

** W. E. Le Gros Clark, *The Anatomical Pattern as the Essential Basis of Sensory Discrimination*. Oxford, 1947.

from the centre of the cornea, where there are only free nerve endings.* Also, it is suggested that the appreciation of the different modalities of cutaneous sensation depend more on the pattern of the impulses arriving at the sensory cortex, including their number and their spatial and temporal arrangement. In the central nervous system the nerve fibres concerned with the transmission of impulses to the thalamus and cerebral cortex run in discrete tracts. The fibres in these tracts and their terminations in the thalamus and cortex appear to be arranged somatotopically, that is they are arranged spatially according to the topographical source of the impulse which they transmit (fig. 821).† Disturbances of sensation associated with nerve block or regeneration of peripheral nerves result from a distortion of the normal pattern.‡

Interceptors.—These include the receptor end-organs in the walls of the viscera and blood vessels. A variety of fibre terminations and end-organs including naked nerve endings, loops and encapsulated organs, has been described in association with the blood vessels and viscera§. Nerve terminals are found in all layers of the visceral walls including the lining epithelium and are numerous in the adventitia of blood vessels. Owing to technical difficulties the precise morphology and nature of many of these endings is still subject to doubt. Typical lamellated corpuscles have been described in the heart, adventitia of blood vessels, pancreas and mesenteries. The morphology of the afferent neurones, including the location of their cell bodies, is similar to that of the neurones in the exteroceptive field. The effector apparatus is represented by glandular epithelial cells and voluntary muscle in the walls of the viscera and blood vessels.

The end-organs and nerve-terminals in the viscera are not, in general, subject to the stimuli which act on the exteroceptors placed at the surface of the body and with certain exceptions do not respond to mechanical and thermal stimuli. Under normal conditions the activities of the viscera are mostly carried out without intruding into consciousness. There is evidence, however, that splanchnic centres are found in the frontal lobe (p. 1043). Tension produced by overstretching or excessive muscular contraction, however, often gives rise to visceral pain, particularly in pathological conditions, which is frequently poorly localised and of the deep seated variety. It is generally believed that such visceral pain is due to the passage of pain impulses along special visceral afferent pathways, but it may also arise from the spread of abnormal stimuli from the visceral to the somatic pathways by means of collaterals. In the cat visceral afferent impulses have been traced through the funiculus gracilis and the medial lemniscus (p. 953) to the thalamus and also bilaterally through the spinothalamic tracts to reach the posterior part of the hypothalamus and caudal part of the thalamus on both sides.||

Baroreceptors are stimulated by changes in the blood pressure. Afferent impulses arising in the wall of the heart itself influence the heart rate, the conductivity and the force of the heart beat. Under pathological conditions impulses from the heart give rise to pain distributed over the left side of the chest and down the left arm.

Proprioceptors.—The proprioceptors are stimulated by the activity of the muscles, movements of joints and changes in the position of the body as a whole or its various parts and are essential for the co-ordination of muscles, the grading of muscular contraction and the maintenance of equilibrium. The vestibular apparatus is considered elsewhere (p. 1284) and only the receptor end-organs in muscles, tendons and joints will be considered here. The functional differences between the various types of proprioceptor endings in muscles and tendons is not clear, but it has been generally believed that neuromuscular spindles and neurotendinous endings are excited by stretching; they are therefore often termed *stretch receptors*, a view which is not wholly tenable. The intrafusal fibres of muscle spindles lie in parallel with the remainder of the muscle fibres and are relaxed when the muscle contracts

* E. H. Knocks, D. C. Sinclair and G. Weddell, *Proc. Roy. Soc. B.*, **141**, 1955.

D. Sinclair, *Brain*, **78**, 1955.

G. Weddell, E. Palmer and W. Pallie, loc. cit.

† O. Bumke and O. Foerster, *Handb. d. Neurologie*, Berlin, **5**, 1936.

‡ D. C. Sinclair, G. Weddell and E. Lander, *J. Anat. Lond.*, **86**, 1952.

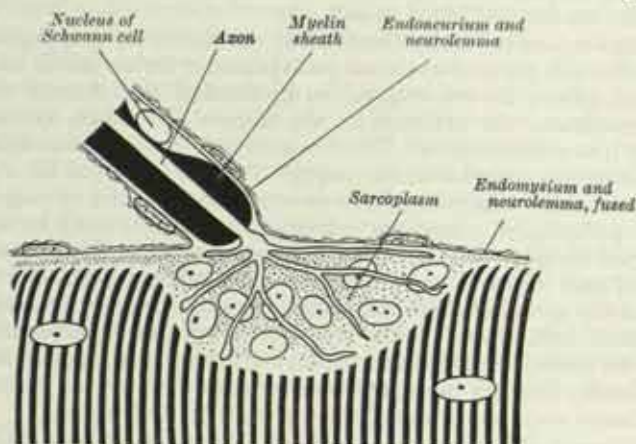
§ For details see G. A. G. Mitchell, *The Anatomy of the Autonomic Nervous System*, Edinburgh and London, 1953, and A. Kuntz, *The Autonomic Nervous System*, 4th Ed., Philadelphia, 1953.

O. Adair, W. A. Geohagan and H. Ungeiwetter, *J. Neurophysiol.*, **15**, 1952.

and extended when the muscle relaxes. When extended the flower-spray or the annulo-spiral endings or both are stimulated and impulses pass along the afferent fibres in the so-called muscle nerve to the central nervous system. These impulses from the muscle spindles are responsible for the stretch reflex,* for when the intrafusal fibres are stretched the resulting impulses excite the muscles' own motor neurones.† This provides a self-regulating mechanism for the maintenance of a constant muscle length and a method for the automatic regulation of the muscle fibres to meet changes in load and in fatigue.‡ The intrafusal muscle fibres receive their motor innervation by fine medullated fibres termed the γ efferents (see p. 918) from the ventral nerve roots. When stimulated the intrafusal fibres enter into slow tonic contraction, stretching the equatorial region of the spindle and stimulating the annulo-spiral endings. The afferent impulses thus produced, in their turn reinforce the stretch reflex and provide a follow-up mechanism for the maintenance of posture (see Muscle tonus, p. 549). Collaterals arising within the spinal medulla from the efferent neurones to the main muscle fibres carry impulses to internuncial neurones which synapse with other anterior horn cells and are believed to carry inhibitory impulses to these and so to the muscles which are not excited.

Apart from the above mentioned there are other receptor end-organs, both unencapsulated and encapsulated, in the deeper connective tissues and in the connective tissues associated with muscles and bones. These include lamellated

FIG. 808.—A diagram of a motor end-plate. After Gutmann and Young.



Note.—The sarcolemma, which is a very thin membrane, is not shown. It blends with the axonal membrane which ensheathes the terminals of the axon.

corpuscles. Some of these respond to pressure changes and vibration whilst others are associated with impulses underlying pain. The sensation of pain arising in these deeper tissues differs in quality and tends to be a dull, aching, poorly localised type when compared with pain impulses originating in nerves in the more superficial tissue, which is sharp and well localised. This may be explained by the sparsity of nerve terminals in the deeper as compared with the superficial tissues.§

Effector endings.—The axons of effector neurones of the somatic system form specialised endings in the skeletal muscles, termed by Kühne, who first described them, *motor end-plates* (fig. 808). Medullated fibres emerge from the rich plexus formed by the terminal branches of the motor nerve to the muscle. Each of these individual fibres, which is the axon of one effector neurone, may supply through its terminal branches as many as one hundred and fifty muscle fibres, although in some muscles concerned with discrete movements, for example, the extrinsic muscles of the eye, the number is much smaller.|| The effector neurone, together with the

* E. G. T. Liddell and C. S. Sherrington, *Proc. Roy. Soc. B.*, **92**, 1924.

† P. H. Hammond, P. A. Merton and G. G. Sutton, *Brit. Med. Bulletin*, **12**, 1956.

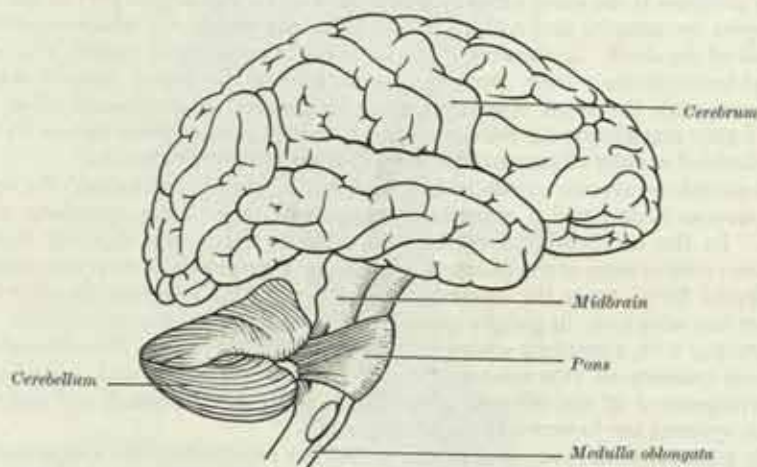
‡ E. Granit and P. A. Merton, *J. Physiol.*, **122**, 1953. P. A. Merton, *Brit. Med. Bulletin*, **12**, 1956.

§ T. Lewis, *Pain*, New York, 1942.

|| C. S. Sherrington, *Selected Writings*, London, 1939.

muscle fibres supplied by it, constitute a *motor unit*. The end-plate consists of a localised patch of granular sarcoplasm lying immediately under the sarcolemma and containing a number of clear nuclei, which may be round or oval in shape. When the terminal nerve fibril reaches the plate, it loses its myelin sheath and its covering endoneurium (p. 41) becomes directly continuous with the endomysium (p. 32) of the muscle fibre. There is no direct continuity between the sarcoplasm of the plate and the axoplasm of the nerve fibril and its terminal branches, and the relationship is one of contact between the axonal membrane and the sarcolemma.* Following experimental section of a motor nerve, the denervated motor end-plates show no degenerative changes in their nuclei or sarcoplasm, which are clearly constituent parts of the muscle fibre. The sympathetic fibres running in motor nerves are probably all distributed to the blood-vessels of the muscle.

FIG. 809.—A scheme showing the connexions of the several parts of the brain.
(After Schwalbe.)



The effector neurones of the autonomic system end either by blending with the protoplasm of plain muscle fibres, or in close association with the epithelial cells of the glands which they supply.

PARTS OF THE NERVOUS SYSTEM

The brain and spinal medulla constitute the *central nervous system* and are situated in the central axis of the body. Twelve pairs of cranial nerves arise from the brain and thirty-one pairs of spinal nerves arise from the spinal medulla; together these form the *peripheral nervous system*.

The *spinal medulla* occupies the upper two thirds of the vertebral canal and is continuous at the foramen magnum with the medulla oblongata. Its walls are relatively thick and enclose a narrow central cavity termed the central canal.

The *brain* (fig. 809) lies within the cranial cavity and comprises the rhombencephalon which includes the medulla oblongata, pons and cerebellum, the mesencephalon or midbrain, and the prosencephalon which consists of the diencephalon and telencephalon. The telencephalon is composed of the two cerebral hemispheres which together constitute the cerebrum and a small median connecting portion. The midbrain, pons and medulla oblongata connect the prosencephalon with the spinal medulla and together constitute the *brain stem*. The account of the development of these parts has already been given (pp. 125–144) and will be found to be of considerable assistance to the understanding of their relationships to one another.

The *medulla oblongata* is the lowest part of the brain and rests on the lower part of the basilar portion of the occipital bone. It is continuous below with the spinal medulla and above with the pons. The *pons* rests on the upper part of the basilar portion of the occipital bone and the dorsum sellæ. It is considerably thicker than

* P. E. Gutmann and J. Z. Young, *J. Anat.*, 78, 1944. J. D. Robertson, *J. Biophys. Cytol.*, 2, 1956.

the medulla oblongata and is distinguished from it by the broad band of transversely coursing fibres which forms a considerable protuberance on its ventral surface. The *cerebellum*, which consists of two *hemispheres* united by a median *vermis*, lies posterior to the pons and medulla oblongata and occupies the major part of the posterior cranial fossa. It is connected to the medulla oblongata below, the pons in the middle and the midbrain above. The cavity of the rhombencephalon has expanded to form the *fourth ventricle*. This is continuous through a narrow central cord in the lower part of the medulla oblongata with the central canal of the spinal medulla. The *midbrain* is a relatively short constricted part of the brain intervening between the rhombencephalon and the prosencephalon. Its walls are thick and its cavity is reduced to a narrow canal, termed the *cerebral aqueduct*, which connects the third and fourth ventricles.

The *diencephalon* is almost completely hidden from surface view by the cerebrum. Its lateral wall is greatly thickened to form the thalamus while its cavity is reduced to a deep slit which constitutes the major portion of the *third ventricle* of the brain.

The *cerebrum* is the most rostrally placed and by far the largest part of the brain. It occupies the anterior and middle cranial fossae and almost the whole concavity of the vault of the skull. It consists of two large ovoid convoluted masses, termed the cerebral hemispheres. Each contains a cavity termed the *lateral ventricle* which is continuous with the third ventricle. Each hemisphere is composed of an outer layer of grey matter termed the *cortex* and a central core of *white matter* in which are embedded masses of grey matter, constituting the *corpus striatum*.

The *peripheral nervous system* includes a somatic component termed the *cerebrospinal nervous system* and a splanchnic component termed the *autonomic nervous system*. In the cerebrospinal system the efferent fibres pass directly from the central nervous system to the effectors. In the autonomic nervous system, however, the efferent fibres from the central nervous system do not pass directly to the effectors but terminate in ganglia placed outside the central nervous system where they synapse with a neurone whose axon passes to the effector. The efferent pathway thus consists of two neurones termed the *preganglionic* and *postganglionic*. The arrangement of the afferent fibres however in cerebrospinal and autonomic nervous systems are believed to be comparable.

The autonomic nervous system can be further subdivided into *sympathetic* and *parasympathetic* parts. The preganglionic fibres of the sympathetic part spring from a strictly limited region of the spinal medulla which extends from the first thoracic to the second or third lumbar segments. The preganglionic fibres of the parasympathetic part leave the central nervous system in certain of the cranial nerves (3rd, 7th, 9th, 10th and 11th) and the second, third and fourth sacral nerves. The efferent preganglionic fibres of these two parts of the autonomic nervous system are therefore often termed the *thoracolumbar* and *craniosacral* outflows respectively. A detailed description of the autonomic nervous system is given on pp. 1123-1124.

THE CENTRAL NERVOUS SYSTEM

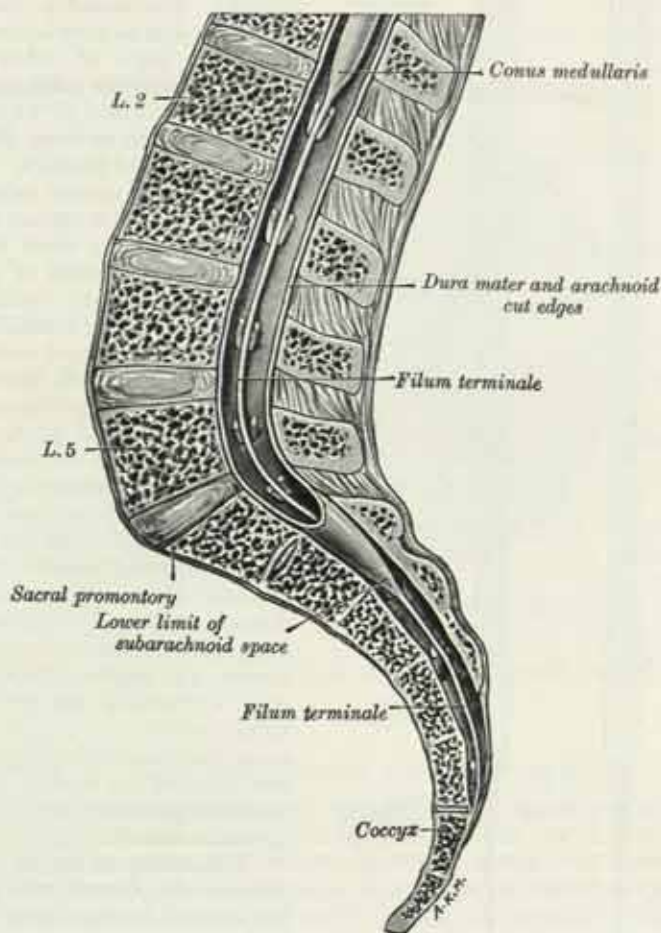
The structures which constitute the central nervous system include the spinal medulla, the medulla oblongata, the pons, the cerebellum, the mid-brain and the cerebrum. It will be found convenient to commence with the study of the spinal medulla, which represents the simplest and most primitive part of the central nervous system, and, although it contains the terminals of the great efferent pathways, it also contains the origins and early stages of a large number of the great afferent pathways.

THE SPINAL MEDULLA (CORD)

The *spinal medulla* is the elongated, nearly cylindrical, part of the central nervous system which occupies the upper two-thirds of the vertebral canal. Its average length in the male is 45 cm.; its weight is about 30 gms. It extends from the level of the upper border of the atlas vertebra to that of the lower border of the first lumbar vertebra, or upper border of the second, as a rule, but its lower end may sometimes be found as high as the lower border of the twelfth thoracic vertebra or as

low as the upper border of the third lumbar vertebra. Its position varies with the movements of the vertebral column, being raised slightly when the column is flexed. It has this degree of mobility because it does not occupy the whole of the vertebral canal and is ensheathed in three protective membranes termed the dura mater, arachnoid and pia mater which are separated from each other by fluid-containing spaces, the subdural and subarachnoid spaces (pp. 1079-1088). Above, the spinal medulla is continuous with the medulla oblongata; below, it tapers off

FIG. 810.—A median sagittal section through the lower part of the vertebral column, showing the lower end of the spinal medulla and the filum terminale.



Note.—The subarachnoid space has been laid open down to the lower border of the first sacral vertebra.

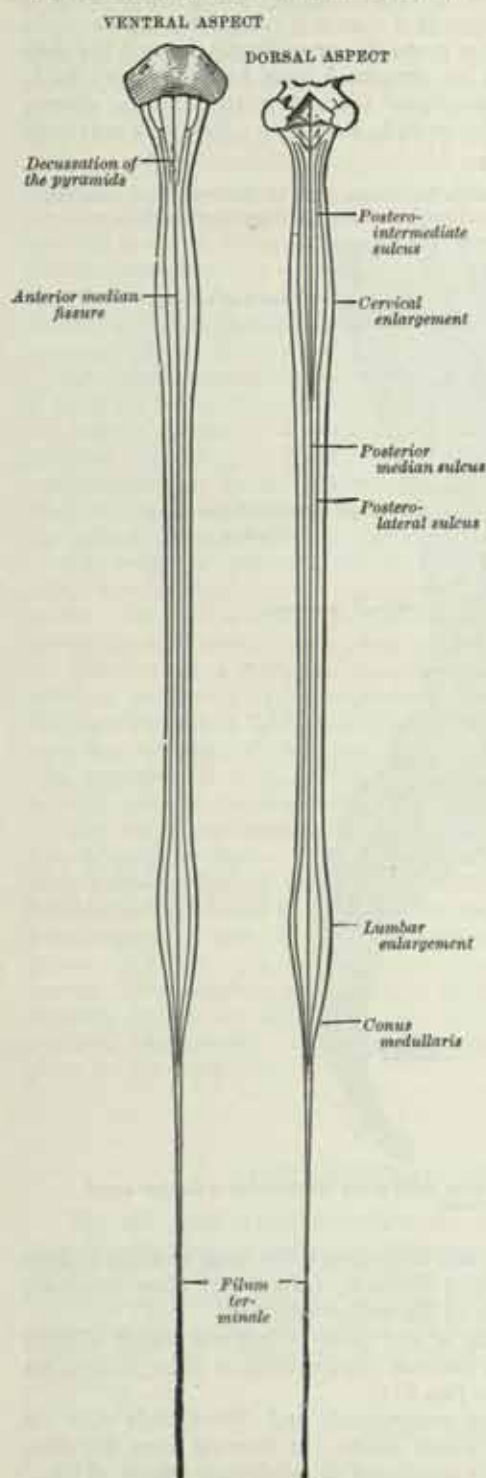
rapidly into a conical extremity (figs. 810 and 813) termed the *conus medullaris*, from the apex of which a delicate non-nervous filament, named the *filum terminale*, descends to the back of the first segment of the coccyx (fig. 810).

Enlargements.—The spinal medulla is not quite cylindrical, being slightly flattened from before backwards; it also presents two swellings or enlargements, an upper or cervical, and a lower or lumbar (fig. 811).

The *cervical enlargement* is the more pronounced, and corresponds with the attachments of the large nerves of the upper limbs. It extends from the third cervical to the second thoracic segment, its maximum circumference (about 38 mm.) being at the level of the roots of the sixth pair of cervical nerves (See p. 931).

The *lumbar enlargement* corresponds with the attachments of the nerves of the lower limbs. It begins at the level of the ninth thoracic vertebra, and reaches its maximum circumference—about 33 mm.—opposite the last thoracic vertebra, below which it tapers rapidly into the conus medullaris.

FIG. 811.—Diagrams of the spinal medulla.

**Fissures and sulci (fig. 811).—**

An anterior median fissure and a posterior median septum incompletely divide the spinal medulla into two symmetrical parts, which are joined across the median plane by a commissural band of nervous matter.

The *anterior median fissure* has an average depth of about 3 mm., but is deepest in the lower part of the spinal medulla. It contains a reticulum of pia mater, and its floor is formed by a transverse band of white matter, termed the *anterior white commissure*, which is perforated by blood-vessels on their way to or from the central part of the spinal medulla.

The *posterior median sulcus* is very shallow; from it a septum of neuroglia reaches rather more than half-way into the substance of the spinal medulla; the septum varies in depth from 4 to 6 mm., diminishing considerably as it is traced downwards.

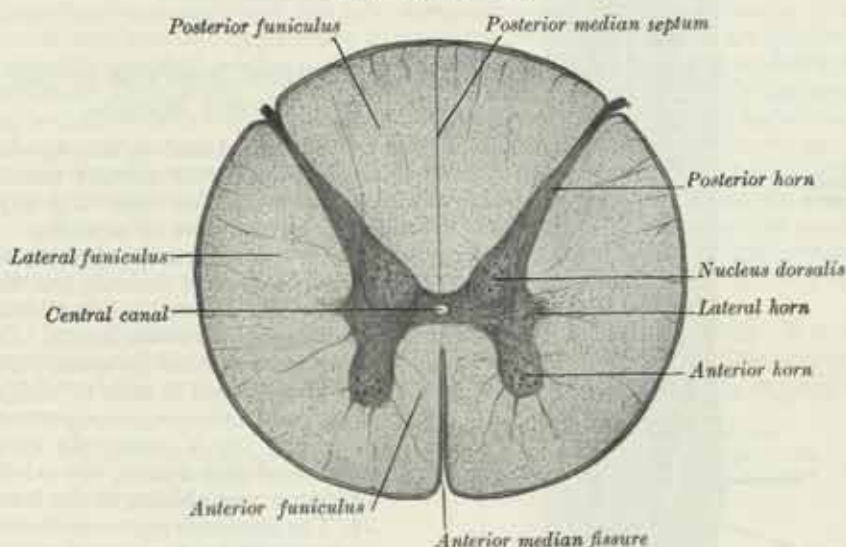
On each side of the posterior median sulcus and at a short distance from it, the dorsal nerve-roots are attached along a vertical furrow, termed the *posterolateral sulcus*. The portion of the spinal medulla which lies between this and the posterior median septum is named the *posterior funiculus*. In the cervical and upper thoracic regions the surface of this funiculus presents a longitudinal furrow, the *postero-intermediate sulcus*: this marks the position of a septum which extends into this posterior funiculus and subdivides it into two fasciculi—a medial, named the *fasciculus gracilis*; and a lateral, the *fasciculus cuneatus* (fig. 817).

The portion of the spinal medulla between the posterolateral sulcus and the anterior median fissure is termed the *anterolateral region*. The white matter in this region can be further subdivided into an *anterior* and *lateral funiculus*. The former lies between the anterior median fissure and the most lateral of the bundles of the ventral nerve roots which emerge on the anterolateral aspect of the spinal medulla; the latter lies between the ventral nerve roots and the posterolateral sulcus (fig. 812). In the upper part of the cervical region a series of nerve-roots passes outwards through

the lateral funiculus; these unite to form the spinal root of the accessory nerve, which ascends and enters the cranial cavity through the foramen magnum (fig. 827), and conveys to the accessory nerve the fibres which supply the sternocleidomastoid and trapezius muscles.

The *filum terminale* (figs. 810, 813) is a delicate filament, about 20 cm. long, continued downwards from the apex of the conus medullaris. Its upper part, or *filum terminale internum*, about 15 cm. long, is continued within a tubular sheath of dura and arachnoid mater, and reaches as far as the lower border of the second sacral vertebra. Its lower part, or *filum terminale externum*, is closely invested by, and adherent to, the dura mater; it descends from the apex of the tubular sheath of dura mater and is attached to the back of the first segment of the coccyx. The *filum terminale* consists mainly of fibrous tissue, continuous above with that of the pia mater, but adhering to the outer surface of its upper part are a few strands of nerve-fibres which probably represent the nerve-roots of rudimentary second and third

FIG. 812.—A transverse section through the mid-thoracic region of the spinal medulla. $\times 8$.



coccygeal nerves; further, the central canal of the spinal medulla is continued downwards into it for 5 or 6 mm.

THE SPINAL NERVES AND NERVE-ROOTS

Thirty-one pairs of spinal nerves spring from the spinal medulla at intervals along its length, each nerve having a ventral and a dorsal root (fig. 814). The pairs of spinal nerves are grouped as follows: cervical 8, thoracic 12, lumbar 5, sacral 5 and coccygeal 1, and for convenience of description the spinal medulla is divided into cervical, thoracic, lumbar and sacral regions, corresponding with the attachments of the different groups of nerves. The portion of the spinal medulla to which a pair of nerves is attached is termed a *segment*, although there is no trace of segmentation visible on the surface of the adult structure.

The uppermost spinal nerve-roots cross the subarachnoid space (p. 1083) nearly horizontally but the remainder pass more and more obliquely downwards so that the roots of the lumbar and sacral nerves pursue an almost vertical course to their intervertebral foramina. Below the termination of the spinal medulla at the level of the lower border of the first lumbar vertebra these nerve-roots form a sheaf around the *filum terminale* in the lower part of the subarachnoid space. The sheaf bears a resemblance to a horse's tail and is called the *cauda equina* on this account (fig. 813).

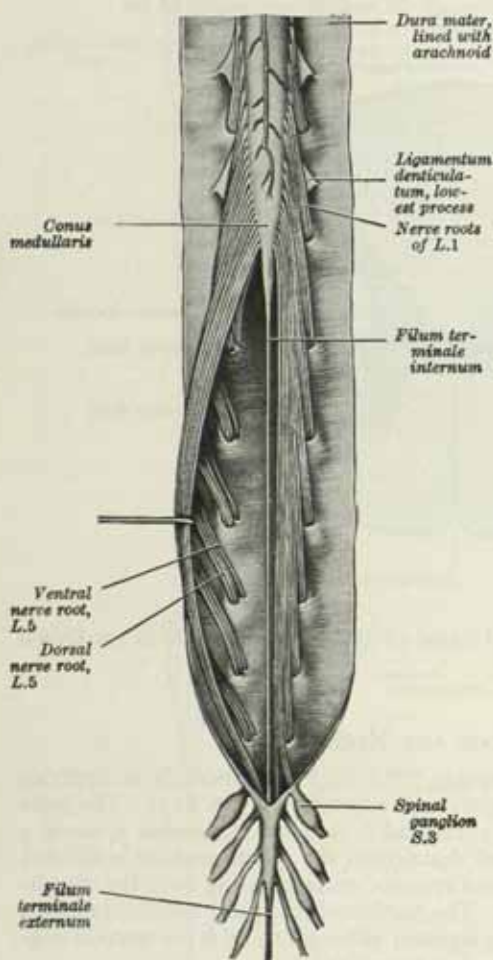
The *ventral nerve-root* consists of somatic and splanchnic efferent fibres which are the axons of cells in the spinal medulla. A short distance from their origins these axons are invested with medullary sheaths and passing outwards emerge in bundles arranged in two or three irregular rows over a distance of about 3 mm. across the side of the spinal medulla.

The *dorsal nerve-root* is characterised by an oval swelling termed a spinal

ganglion. Proximal to this it separates into 6 or 8 fasciculi which fan out to be attached in line or series along the postero-lateral sulcus. Each dorsal nerve-root consists almost entirely * of afferent fibres which arise from the nerve cells of the corresponding spinal ganglion. Each ganglion cell gives off a single fibre which divides in a T-shaped manner into two processes, medial and lateral. The medial processes pass into the spinal medulla as the dorsal roots of the spinal nerves, whilst the lateral processes are directed towards the periphery.

Distal to the ganglion the dorsal root joins the ventral nerve-root to form a *spinal nerve*.

FIG. 813.—The lower end of the spinal medulla, the filum terminale and the cauda equina exposed from behind. The dura mater and the arachnoid have been opened and spread out.



INTERNAL STRUCTURE OF THE SPINAL MEDULLA

The spinal medulla is composed of grey and white nervous matter, in both of which there is a supporting framework of neuroglia.

The **grey matter** [substantia grisea] is situated centrally and has the form of a fluted column which runs through its whole length. On transverse section of the spinal medulla this column is seen to consist of right and left symmetrical portions connected by a transverse commissure of grey matter, the whole bearing a resemblance to the letter **H**. The transverse grey commissure is traversed by the central canal, which is just visible to the naked eye. Each lateral portion is shaped like a crescent with its concavity directed laterally, and, as seen on transverse section, can be divided into anterior and posterior horns according to their relation to the transverse grey commissure. A projection from the lateral surface of the grey matter opposite the transverse grey commissure is also present in some regions and constitutes the lateral horn. The terms ventral, dorsal and lateral horns refer only to the appearances in transverse sections.

When the grey matter of the spinal medulla as a whole is under consideration, the terms anterior, posterior and lateral grey columns are more appropriate.

The **anterior column** is directed forwards and somewhat laterally. It is short but broad in proportion and fails to reach the surface of the spinal medulla, from which it is separated by the anterior funiculus. The posterior part of the anterior column is termed the *base*, and the anterior part the *head*, but they are not separated from each other by any definite constriction.

The **posterior column** is directed backwards and somewhat laterally. It is long and slender, and reaches almost as far as the posterolateral sulcus, from which it is separated by a thin coating of white matter, named the *dorsolateral tract*. It consists of a *base*, which is continuous with the base of the anterior column, a con-

* J. Z. Young and S. Zuckerman have suggested that 3% of these fibres are efferent. *J. Anat., Lond.* 71. 1936-37.

stricted *neck*, and an oval or fusiform *head*, the *apex* of which is capped by a mass of translucent nervous tissue, termed the *substantia gelatinosa*. This gelatinous substance is V-shaped or crescentic in transverse section, and contains both neuroglia and nerve-cells.

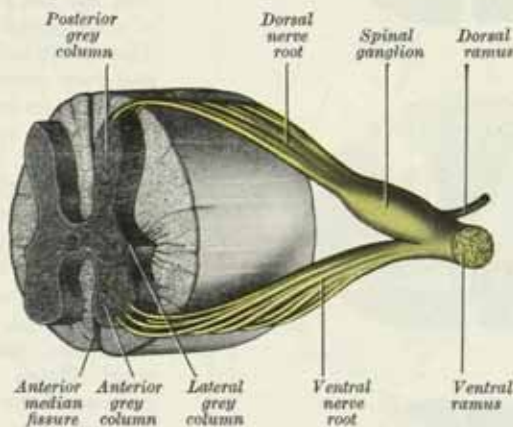
The **lateral column** is small and pointed; it extends through the thoracic and first lumbar segments of the spinal medulla but does not occur elsewhere.

The limits of the grey matter are, as a rule, clearly defined, but in the cervical region strands of grey matter extend into the lateral funiculus, where they form a network, termed the *formatio reticularis*, opposite the base of the posterior column. Traces of this reticular formation can be seen also in lower segments.

The quantity of grey matter and the form it presents on transverse section vary at different levels (fig. 815). In the thoracic region the grey matter is small in amount, not only absolutely, but relatively to the surrounding white matter. In the cervical and lumbar enlargements, to which the nerves of the limbs are attached, it is greatly increased; so that in the latter, and especially in the *conus medullaris*, its proportion to the white matter is greater than elsewhere (fig. 815). In the cervical region the posterior horn is comparatively narrow, while the anterior horn is broad and expanded; in the thoracic region, the anterior and posterior horns are narrow, and the lateral horn is evident; in the lumbar enlargement the anterior and posterior horns are both broad; while in the *conus medullaris* the grey matter assumes the form of two oval masses, one in each half of the spinal medulla, connected together by a broad grey commissure. The motor nerves to the limbs arise from groups of nerve-cells which occupy the lateral parts of the broad anterior grey columns in the cervical and lumbar enlargements.

The **central canal** traverses the entire length of the spinal medulla. It is continued upwards through the lower part of the medulla oblongata and opens into the fourth ventricle of the brain; below, it reaches for a short distance (5-6 mm.) into

FIG. 814.—A diagram of a portion of the spinal medulla to show the mode of formation of a typical spinal nerve. The grey matter is shown in relief. (After Testut.)



the *filum terminale*. In the lower part of the *conus medullaris* it exhibits a fusiform dilatation (the *terminal ventricle*), which has a vertical measurement of from 8 to 10 mm., is triangular on cross-section with its base directed forwards, and tends to undergo obliteration after the age of forty years.

In the cervical and thoracic regions the central canal is situated in the anterior part of the spinal medulla; in the lumbar enlargement it is near the middle, and in the *conus medullaris* it is placed more dorsally. It is filled with cerebrospinal fluid, and lined with ciliated, columnar epithelium (*ependyma*), which is encircled by a band of gelatinous substance, termed the *substantia gelatinosa centralis*. This gelatinous substance consists mainly of neuroglia, but contains a few nerve-cells and nerve-fibres; it is traversed by processes from the deep ends of the ependymal cells.

The grey matter surrounding the canal is named the *grey commissure*. The

FIG. 815.—Transverse sections through the spinal medulla at different levels. $\times 4$. (After Alexander Bruce.)



C.3.



C.6.



T.6.



L.3.



S.2.

part in front of the canal is thin, and in contact with the white commissure: it contains a pair of longitudinal veins, one on each side of the median plane. The part behind the canal reaches from the central canal to the posterior median septum; it is thinnest in the thoracic region, and thickest in the conus medullaris.

The structure of the grey matter.—The grey matter of the spinal medulla consists of neuroglia, blood vessels, nerve fibres and nerve cells. The predominance of nerve cells is responsible for its grey appearance. The neuroglia is arranged in the form of a sponge-like network but in the gelatinous substance around the central canal and on the apices of the posterior columns it is very much condensed. The nerve fibres include collaterals and terminals from fibres in the white matter, some of which have crossed from the opposite side, the terminations of some of the dorsal root fibres, the commencements of the fibres in the ventral root and the axons and dendrites of cells in the grey matter itself. The nerve cells are multipolar and vary greatly in size and are of two types termed Golgi type I and Golgi type II neurones, which differ in the length and location of their axons. The axons of the Golgi type I neurones are long and pass into the white matter where they constitute the fibres of the ventral roots of the spinal nerves, the fibre tracts of the white matter and commissural fibres. Golgi type II neurones have short axons which do not leave the grey matter. Most of the neurones are confined to one segment and are therefore *intra-segmental* neurones. They form internuncial neurones on the spinal reflex arcs between the sensory neurones entering by the dorsal roots and the motor neurones of the anterior grey

column and also between the terminals and collaterals of the fibres of the descending tracts in the white matter (p. 939) and the motor neurones. The axons of some of the Golgi type II neurones pass through the grey matter to terminate at higher or lower levels and so serve to link adjacent parts of the spinal medulla with one another and are therefore *intersegmental* neurones.

The nerve-cells of the grey matter may be classified into three main groups

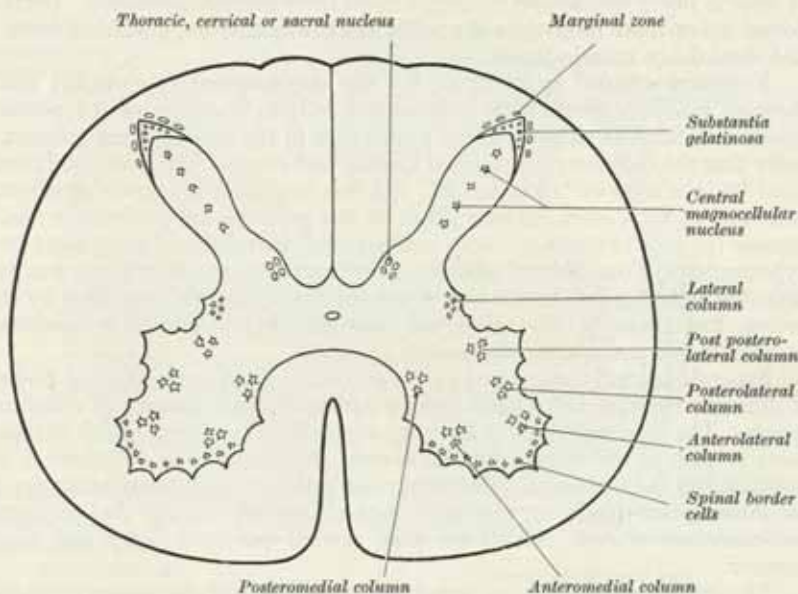
according to their position, viz.: the cells of the anterior column, the cells of the lateral column, and the cells of the posterior column.

(A) **The nerve-cells of the anterior grey columns.**—The anterior grey columns contain the cells of the effector neurones whose axons form the fibres of the ventral roots which supply the voluntary muscles. These are mainly large multipolar cells of $25\ \mu$ diameter or over. In addition there are small oval cells with a diameter of $15\text{--}25\ \mu$ which are believed to be concerned with the innervation of the intrafusal fibres of the muscle spindles. All the multipolar cells are not however motor in function nor are all the small cells concerned with the muscle spindles.

The cells of the anterior grey column tend to be aggregated into longitudinal columns and in transverse sections appear as clusters.* The precise arrangements of these columns, their homologies in the different regions of the spinal medulla and their functional significance are however uncertain.†

In the cervical and lumbar enlargements the large multipolar cells are arranged in two main groups, medial and lateral. The medial group includes an antero-medial and a postero-medial column. The cells of the antero-medial column give rise to the axons which innervate the vertebral muscles supplied by the dorsal rami of the spinal nerves and the cells of the postero-medial column give origin to the axons for the ventral rami and are concerned with the innervation of the remaining musculature of the trunk. The lateral group of cells is presumably concerned with the innervation of the limb musculature. This group can be subdivided into antero-lateral, postero-lateral and post postero-lateral columns which have been related to the innervation of the musculature of the shoulder and arm, forearm and hand segments in the cervical enlargement and to the corresponding segments of the lower limb in the lumbar enlargement ‡ (fig. 816).

FIG. 816.—Diagram of a transverse section through the spinal medulla to show the positions of the principal cell columns.



Elsewhere in the spinal medulla the lateral group of cells is absent but antero-medial and postero-medial columns of large multipolar cells can be distinguished. Though these are continuous with the corresponding columns in the cervical and lumbar enlargements their homologies have been questioned. Beyond these enlargements the cells which give origin to the dorsal and ventral rami of the spinal nerves are scattered throughout the entire anterior grey column, though the cells of origin of

* L. Jacobsohn, *Abh. Preuss. Akad. Wiss., Phys. Math. K.L.*, 1909, and A. Bruce, *A Topographical Atlas of the Spinal Cord*, London, 1901.

† G. J. Romanes, in *The Spinal Cord*, London, 1953.

‡ J. M. Sprague, *Amer. J. Anat.*, 82, 1958.

the fibres of the ventral rami are most numerous dorsilaterally and those for the dorsal rami are most numerous ventro-laterally. Only the most ventrally placed cells are solely concerned with the innervation of the dorsal musculature of the trunk.

The small oval cells of the grey matter are scattered throughout the anterior column but are also concentrated in a well-marked nucleus on the ventral edge of the grey matter [in the lumbar region where they are called the spinal border cells].*

Functional significance of the cells of the anterior column.—The motor cells in the anterior grey column constitute the last neurone in the somatic efferent pathway (*final common motor path*). Their axons innervate striated muscle fibres; some of them are concerned exclusively with the innervation of the intrafusal fibres of the muscle spindles (see p. 926). Their synaptic connexions are exceedingly numerous. In the cat it has been estimated that the number of end-bulbs on one of these cells, including its axon hillock, the adjoining parts of the axon itself and the larger dendrites, exceeds a thousand in the case of a cell of average size.† They receive nerve-impulses from a variety of sources and transmit them to the muscles, which can thus be brought under the control of the cerebral cortex, the cerebellum, the corpus striatum, the vestibular and visual apparatus, etc. Destruction of the motor cells, or the division of their axons, is followed by the phenomena of muscular degeneration, *phenomena which do not result from any other lesion or combination of lesions of the nervous system* but the explanation of this is uncertain. Destruction of the great efferent pathway from the brain will cause paralysis and, after a period, atrophy of the muscle fibres possibly from disuse, but the atrophied muscle retains its peculiar structure.

For local reflexes the anterior column cells are linked by internuncials with posterior column cells of the same, and of adjoining segments, and the constant stream of impulses which they receive from this source is responsible for the reflex activity of muscle fibres and has an influence upon their normal myotonus. Section of the dorsal nerve-roots interrupts the reflex arc and, therefore, abolishes reflex activity, and diminishes muscle tonus.

Volitional control is exercised by the corticospinal (pyramidal) tract acting through synapses made with internuncial cells in the base of the posterior grey column, which link them with the motor cells in the anterior grey column. But in order that the muscles may respond rapidly and effectively to volitional control they must be in a state of 'ideal tonus', and this condition is usually attributed to the influence of the cortex. Destruction of the great motor pathway in the internal capsule (p. 1070) results not only in the loss of all volitional movement but also in hypertonicity of the affected muscles. This increase in muscle tonus was previously regarded as being due to the loss of the inhibitory control exercised by the motor cortex, but there is now evidence that the hypertonicity is associated with damage to the extrapyramidal system (p. 1077).

Synergic control is exercised by the cerebellum and is essential for co-ordination of different muscles and muscle groups during the performance of volitional movements. The efferent pathway from the cerebellum (p. 1077), which is regarded by some as part of the extrapyramidal system, passes to the red nucleus in the mid-brain and to the thalamus. Thereafter the pathway taken is uncertain (p. 982) but its interruption leads to muscular inco-ordination during the performance of voluntary movements, which are then carried out in a jerky and exaggerated manner.

The corpus striatum is an important constituent of the extrapyramidal system (p. 1076) and may possibly exercise control over automatic associated movements (p. 1067): its efferent pathways are discussed on p. 1066. In some cases of hemiplegia, a patient, paralysed in the upper and lower limbs of the same side so far as volitional control is concerned, may, especially on yawning when waking from sleep, stretch both arms above his head. This movement is carried out unconsciously and always in association with the limb of the opposite side; it has been explained as an automatic associated movement inaugurated by the corpus striatum, but it may also be ascribed to the innervation of the muscles on the affected side by the cortex of the contralateral hemisphere (p. 942).

* S. Cooper and C. S. Sherrington, *Brain*, 63, 1940.

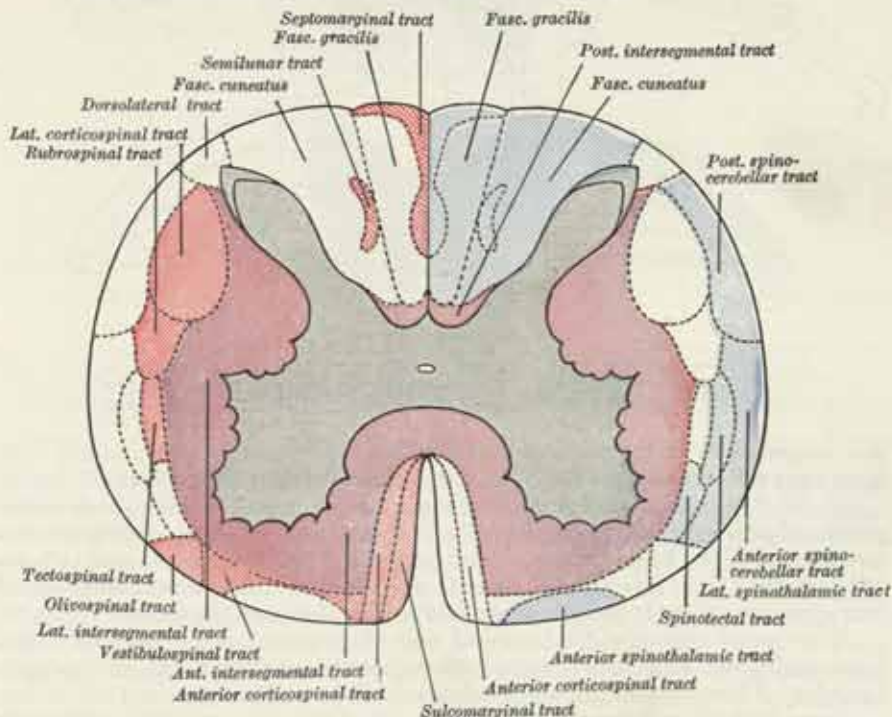
† M. L. Barr, *J. Anat., Lond.*, 74, 1939.

The vestibular apparatus controls unconscious equilibratory movements. The efferent pathway runs in the vestibulospinal tract direct from the lateral nucleus of the vestibular nerve to the cells in the anterior grey column. The visual apparatus exerts its influence through the tectospinal tract (see p. 994).

(B) **The cells in the lateral grey column.**—These cells are smaller than those in the anterior grey column. On transverse section they constitute the *intermediolateral* group of cells, which extends from the first thoracic to the first or second lumbar segment and reappears again in the second, third and fourth sacral segments. In the longer upper part of its extent this cell-group is responsible for the surface projection of the lateral grey column, and its axons pass out in the ventral nerve-roots as pre-ganglionic sympathetic fibres (p. 1201), and traverse the white rami communicantes to reach the sympathetic gangliated trunk. There, or in a more peripheral ganglion, they form synapses with neurones which send their axons, as postganglionic fibres (p. 1201), to glands and cardiac or unstriated muscle. In the sacral part of its extent this cell-group is not clearly demarcated and produces no surface projection. Its axons traverse the ventral nerve-roots and ventral rami of the corresponding sacral nerves and eventually constitute the 'pelvic splanchnic nerves' (p. 1200), which represent the sacral contribution to the parasympathetic system.

It should be remembered that this cell-group is a derivative of the dorsal part of the basal lamina (fig. 140), and it retains the same relative position in the adult.

FIG. 817.—A composite diagram of the principal tracts of the white matter of the spinal medulla. The ascending tracts are shown in blue on the right side of the figure; the descending tracts are shown in red on the left side, and the intersegmental tracts are shown in mauve on both sides.



(C) **Nerve-cells of the posterior grey column.**—In general these are smaller than the other cells of the grey matter and belong to internuncial or connector neurones. As in the anterior grey column they are not uniformly distributed but are arranged in clusters which extend as columns along the length of the spinal medulla. Some of these columns are more clearly defined than others.*

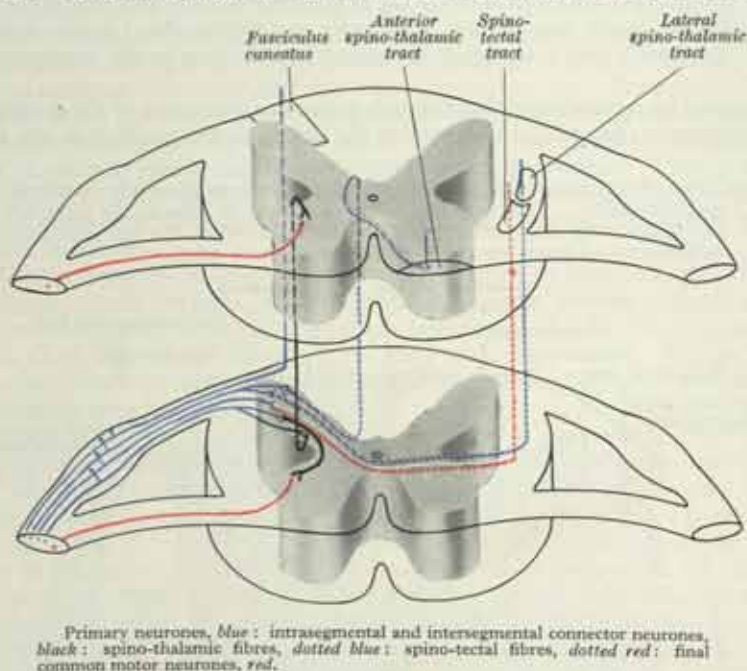
Capping the posterior grey column is a narrow marginal zone containing large

* For details see O. Larsell, *Anatomy of the Nervous System*, 2nd Edition, New York, 1951, and F. A. Mettler, *Neuroanatomy*, 2nd Edition, London, 1948.

spindle-shaped or polygonal cells and deep to this the *substantia gelatinosa*. This consists of large numbers of closely packed cells intermingled with numerous bundles of fine nerve fibres from the dorsal nerve roots and is seen as a pale, opalescent zone in Weigert preparation. It extends the entire length of the spinal medulla and is continuous above, in the medulla oblongata, with the nucleus of the spinal tract of the trigeminal nerve.

A second well-defined column of nerve cells, termed the *thoracic nucleus* occupies the medial part of the base of the posterior grey column in the thoracic and upper lumbar segments of the spinal medulla. It is oval in shape and over much of its length forms a conspicuous projection at the base of the posterior column. It is cut off from the rest of the grey matter by a curved bundle of fibres which will synapse around its cell. The thoracic nucleus is composed of large and medium-sized oval or piriform nerve cells with coarse Nissl granules which are often few in number

FIG. 818.—A diagram to show the chief exteroceptive pathways in the spinal medulla.



and ranged close to the nucleus, which is frequently eccentric in position. The individual cells are surrounded by basket-like networks of nerve fibres.

In the mid-cervical and mid-sacral region of the spinal medulla there are two groups of cells constituting the *cervical* and *sacral nuclei* which occupy the postero-medial part of the base of the posterior column. These consist of small cells and although they lie in line with the thoracic nucleus their cells differ morphologically and apparently there is no close functional relationship between them.

The central regions of the head and neck of the posterior grey column contain large multipolar cells which extend throughout the entire length of the spinal medulla. These constitute the *central magnocellular nucleus*.

Some authorities believe that the nerve cells of the entire spinal grey matter are arranged in a series of superimposed laminae from dorsal to ventral, the succeeding laminae being differentiated from one another by the characters and arrangement of their contained cells.*

From the functional point of view most of the Golgi type I neurones in the posterior column can be grouped as follows:

(a) *Neurones whose axons are destined for other segments of the spinal medulla.*—These cells are scattered throughout the posterior horn. Their axons pass into the intersegmental tracts of the white matter of the same and the opposite sides and then

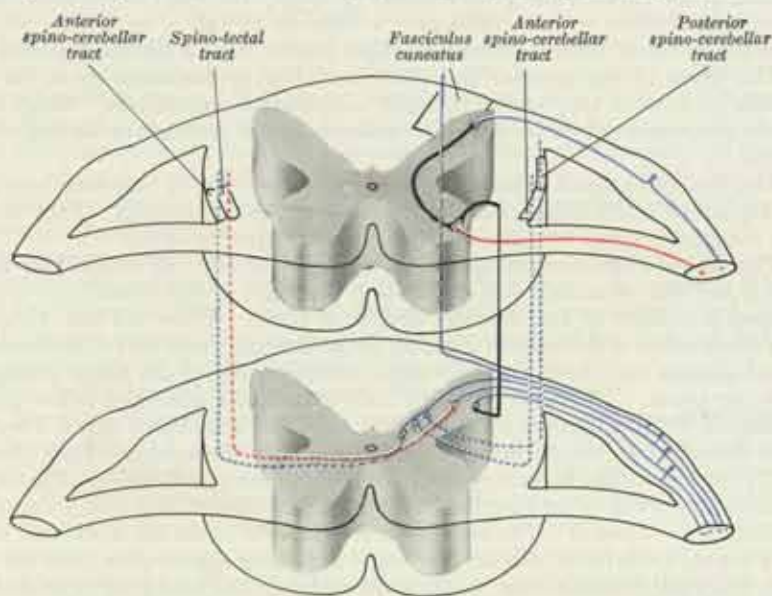
* B. J. Rexed, *J. Comp. Neurol.*, 96, 1952.

turn upwards or downwards to reach a higher or lower segment of the spinal medulla, where they form synapses. By means of these connexions sensory impulses coming in via any dorsal nerve-root may result in a motor response involving a number of segments.

(b) *Neurones whose axons are destined for the cerebellum.*—These belong to the proprioceptive system and the cells are situated in the dorsal nucleus or elsewhere. The axons of most of them pass into the peripheral part of the lateral funiculus of the same or opposite side and there ascend in the *anterior* and *posterior spinocerebellar* tracts. Through these pathways proprioceptive impulses reaching the central nervous system from the muscles and joints via fibres of the dorsal roots of spinal nerves or via collaterals from them, pass to the cerebellum so that they can play their part in the mechanism of muscular co-ordination.

(c) *Neurones whose axons are destined for the thalamus.*—The cells of most of these are probably to be found in the substantia gelatinosa although it has been

FIG. 819.—A diagram to show the chief proprioceptive pathways in the spinal medulla.



Primary neurones, blue: intrasegmental and intersegmental connector neurones, black: spino-cerebellar neurones, dotted blue: spino-tectal neurones, dotted red: final common neurones, red.

claimed that they occur also in the central magnocellular nucleus.* Their axons cross to the opposite side of the spinal medulla either at once, or after ascending one or two segments, in the posterior funiculus. Those which cross at once form the *lateral spinothalamic tract* (p. 944); those which delay their crossing form the *anterior spinothalamic tract* (p. 941). It is along the former that impulses concerned with pain and sensations of heat and cold reach the higher centres.

(d) *Neurones whose axons are destined for the mid-brain.*—The axons of these neurones cross to the opposite side of the spinal medulla and ascend in the *spino-tectal tract* of the lateral funiculus. They form the ascending pathway for spinovisual reflexes (p. 944).

The **white matter** of the spinal medulla consists of nerve fibres and neuroglia and surrounds the grey matter; it is white because large numbers of the nerve-fibres are medullated. The nerve-fibres are arranged in three columns: anterior, lateral, and posterior funiculi (fig. 812). The nerve-fibres vary in thickness; the thinnest are found in the fasciculus gracilis, the dorsilateral tract (p. 945), and the central part of the lateral funiculus; the thickest are situated in the fasciculus cuneatus, the anterior funiculus, and in the peripheral part of the lateral funiculus.

The nerve fibres of the white matter consist of (1) fibres to the ventral and from

* O. Larsell, *Anatomy of the Nervous System*, 2nd Edition, New York, 1951.

the dorsal nerve roots, (2) fibres of the anterior and posterior white commissures, (3) fasciculi proprii or association fibres, and (4) fibres inter-connecting the spinal medulla and the brain.

The fibres of the ventral root are the axons of cells in the anterior and lateral grey columns. They pass laterally with a downward inclination through the lateral part of the anterior funiculus to emerge at the anterolateral aspect of the spinal medulla as the bundles of the ventral root. Before leaving the spinal medulla these fibres frequently give off collaterals which re-enter the grey matter and ramify there. The fibres of the dorsal root enter the spinal medulla at the posterolateral sulcus and separate into a medial bundle of coarse, medullated fibres and a lateral bundle of fine medullated and non-medullated fibres. All these divide into ascending and descending branches, many of which, in turn, give collaterals which enter the grey matter and synapse with its cells. The descending branches are short and soon terminate in the grey matter. The ascending branches are grouped into long, intermediate and short fibres. The long fibres of the medial group ascend in the posterior funiculus to the medulla oblongata where they terminate by synapsing with the cells of the cuneate and gracile nuclei (p. 953); the short fibres enter the grey matter and synapse with its cells after a distance of only 5 to 6 mm., while the intermediate fibres, after a somewhat longer course, have a similar destination.

The fibres of the anterior and posterior white commissures cross the spinal medulla in front of and behind the grey commissure respectively. Many are not strictly commissural but are fibres decussating before entering or leaving the grey matter.

The fasciculi proprii contain the axons of Golgi type II neurones which form intersegmental tracts linking different parts of the spinal medulla. They therefore have their origins and terminations in the grey matter (fig. 820.)

The fibres inter-connecting the spinal medulla and the brain, the fasciculi proprii and the ascending and descending branches of the dorsal root fibres are grouped into more or less definite bundles or tracts. These are not recognisable from one another in the natural state, for the individual tracts are not surrounded by special sheaths and there is always some intermingling of the fibres belonging to adjoining tracts. The identity of the individual tracts described below has been established by the following methods. (1) A. Waller discovered that if a bundle of nerve-fibres is cut, the portions of the fibres which are separated from their cells rapidly degenerate and become atrophied. This is known as *Wallerian degeneration*.* Similarly, if a group of nerve-cells is destroyed, the fibres arising from them undergo degeneration. Thus, if the motor cells of the cerebral cortex are destroyed, or if the fibres arising from these cells are severed, a *descending degeneration* from the seat of injury takes place in the fibres. In the same manner, if a spinal ganglion is destroyed, or the fibres which pass from it into the spinal medulla be cut, an *ascending degeneration* occurs in these fibres above the lesion. (2) In the early stages of the development of the nervous system, the nerve-fibres are naked axis-cylinders; groups of nerve-fibres acquire their medullary sheaths at different periods; hence the fibres can be grouped according to the dates at which they receive these sheaths. The first fibres to acquire medullary sheaths are those of the nerve-roots and of the intersegmental tracts; the last, those of the corticospinal tracts (p. 1078). (3) Golgi's method of staining nervous tissues allows the course and mode of termination of the axis-cylinder processes to be followed.

Tracts in the anterior funiculus. 1. **Descending tracts.**—(a) The *anterior corticospinal tract* is usually small, but varies in size inversely with the lateral corticospinal tract. It is present only in the upper part of the spinal medulla; gradually diminishing in size as it descends, it cannot be traced below the middle of the thoracic region. It consists of fibres which arise from cells in the motor area of the cerebral hemisphere, descend uncrossed to the spinal medulla and terminate for the most part by arborising with internuncial neurones in the base of the posterior grey column of the opposite side. These, in turn, link up with motor cells in the anterior grey column (see also p. 915). This tract is found only in man

* Somewhat later a change, termed *chromatolysis*, takes place in the nerve-cells, and consists of the breaking down and ultimate disappearance of the Nissl's bodies. The cell body swells, the nucleus is displaced towards the periphery of the cell, and the part of the axon still attached to the altered cell diminishes in size and atrophies. Under favourable conditions the cell may resume its normal appearance, and its axon may grow again.

and in the anthropoid apes, but its precise significance is unknown. It is sometimes absent.

(b) The *vestibulospinal tract*, which is derived from the large cells of the lateral vestibular nucleus (p. 963), descends in the anterior funiculus; its fibres end around the cells in the anterior grey column. This fasciculus is uncrossed and brings the anterior column cells under the control of the vestibular nuclei of the same side, serving as the efferent path for equilibratory control. The most laterally situated fibres of the vestibulospinal tract have been described as taking origin from the inferior vestibular nucleus of the *opposite side*. Such an arrangement offers an appropriate pathway to ensure the relaxation of the corresponding muscles of the opposite side, when the ipsilateral muscles contract in response to stimulation through the (uncrossed) vestibulospinal fibres.

(c) A small *sulcomarginal tract** adjoins the anterior median fissure.

2. **Ascending tracts.**—The *anterior spinothalamic tract* constitutes an additional pathway for certain elements of tactile and pressure sensibility. The *first neurone fibres* concerned in this pathway enter the spinal medulla from the dorsal nerve-roots and ascend for two, three or more segments in the posterior funiculus before ending in synaptic connexions with cells in the posterior grey column of the same side. According to some authorities,† many of the long ascending (tactile) fibres in the posterior funiculus (p. 945) send *collaterals* into the ipsilateral posterior grey column where they too end in synaptic connexions with cells there. All the *second neurone fibres* of this pathway are the axons of these cells in the posterior grey column and they cross in the white commissure to reach the contralateral anterior funiculus, where they enter the anterior spino-thalamic tract in which they ascend to the medulla oblongata (p. 941). There they appear to mingle with, and become lost amongst the fibres of the medial lemniscus (p. 953).

3. **Intersegmental tracts (fasciculi proprii).**—The remaining fibres of the anterior funiculus constitute the *anterior intersegmental tract*. It consists of longitudinal intersegmental fibres which arise from cells in the grey matter, and, after a longer or shorter course, re-enter the grey matter. Some of the fibres of this tract pass upwards into the medial longitudinal bundle (p. 994).

Tracts in the lateral funiculus.—1. Descending tracts.

(a) The *lateral corticospinal tract* (crossed pyramidal tract) extends throughout nearly the whole length of the spinal medulla. It gradually diminishes in size as it descends, and it ends about the level of the attachment of the third or fourth sacral nerves. On transverse section it appears as an oval area in front of the posterior horn and medial to the posterior spinocerebellar tract (fig. 817); in the lumbar and sacral regions, where the posterior spinocerebellar tract is absent, the lateral corticospinal tract reaches the surface of the spinal medulla. Its fibres arise from cells in the motor area of the cerebral cortex of the *opposite side* (p. 1041). They pass downwards in company with those of the anterior corticospinal tract, but cross to the opposite side in the medulla oblongata and descend in the lateral funiculus of the spinal medulla; they end, like the fibres of the anterior corticospinal tract, on internuncial neurones situated close to the base of the posterior grey column or in the adjoining part of the base of the anterior grey column, and these, in turn, link them to the motor cells of the anterior grey column, usually of several segments of the spinal medulla. In consequence of the interposition of the internuncial neurones, the fibres of the corticospinal tracts correspond not to individual muscles but to associated groups of muscles.‡ It is believed, however, that a few of the fibres may pass direct to the motor cells of the anterior grey column.

The anterior and lateral corticospinal tracts constitute the motor pathway of the spinal medulla. They descend through the internal capsule of the cerebrum, traverse the cerebral peduncle and pons, and enter the pyramid of the medulla oblongata. In the lower part of the pyramid about two-thirds of them cross the

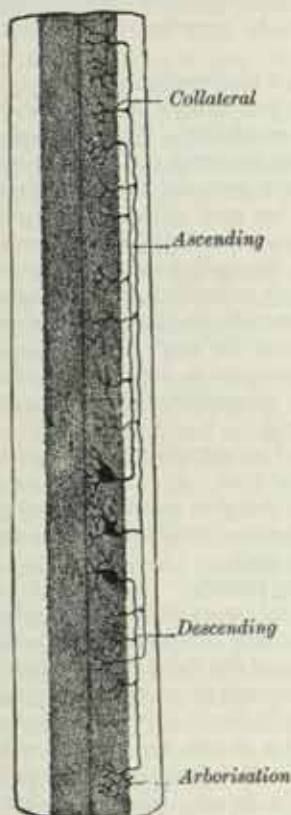
* According to some authorities this tract is formed by the crossed fibres of the tectospinal pathway (p. 942); according to others, the tract is directly continuous with the medial longitudinal bundle at the lower limit of the medulla oblongata.

† S. W. Ranson, *Anatomy of the Nervous System*, 9th Edition. Saunders, Philadelphia, 1953.

‡ Sir E. Sharpey-Schafer, *Proc. Physiological Soc.*, 1899, and E. C. Hoff and H. E. Hoff, *Brain*, 57, 1934.

median plane and run downwards in the lateral funiculus as the lateral corticospinal tract while the remaining fibres do not cross, but are continued into the same side of

FIG. 820.—A diagram showing in longitudinal section the intersegmental neurones of the spinal medulla. The grey and white parts correspond respectively to the grey and white matter of the spinal medulla. (Poirier.)



the spinal medulla, where they form the *anterior corticospinal tract* (fig. 817). There is both experimental and clinical evidence to show that the lateral corticospinal tract contains some fibres which are derived from the cerebral hemisphere of the same side (*uncrossed lateral corticospinal fibres*). It has been estimated* that these fibres constitute one tenth of all the motor fibres. They can be identified as low down as the third sacral segment, and are said to terminate like the crossed fibres but *on the same side*.

(b) The *rubrospinal tract* lies anterior to the lateral corticospinal tract (fig. 817), and on transverse section appears as a somewhat triangular area. Its fibres descend from the mid-brain, where they have their origins in the cells of the red nucleus of the tegmentum of the opposite side (p. 993); they end by forming synapses with the cells in the anterior grey column. Through this tract the cells of the anterior grey column are brought under the influence of the corpus striatum and perhaps also of the cerebellum. The latter exercises synergic control, while the former is the principal subcortical centre associated with the extra-pyramidal system (p. 1076).

(c) The *tectospinal tract* is anterior to the rubrospinal tract; its fibres originate in the superior colliculus of the opposite side,† and end by forming synapses with the cells in the anterior grey column, especially in the cervical segments of the spinal medulla.‡ This tract provides the efferent pathway for spinovisual reflexes (see also p. 944).

(d) The *olivospinal tract* arises in the vicinity of the olivary nucleus in the medulla oblongata and is seen only in the cervical region of the spinal medulla, where it forms a small triangular area at the periphery, close to the most lateral of the ventral nerve-roots. Its fibres form synapses with the cells in the anterior grey column. The precise functional significance of this tract is unknown, but it forms one of the descending pathways of the extrapyramidal

system (p. 1076). In view of the uncertainty which exists with regard to its precise origin in the medulla oblongata, it is frequently termed the *bulbospinal tract*.

2. **Ascending tracts.**—(a) The *posterior spinocerebellar tract* is a flattened band situated at the periphery of the posterior portion of the lateral funiculus; medially it is in contact with the lateral corticospinal tract; behind, with the dorsolateral tract. It begins about the level of the second or third lumbar nerve, increases in size as it ascends, and finally passes to the cerebellum through the inferior cerebellar peduncle. Its fibres are the axons of the cells of the dorsal nucleus of the same side. This nucleus receives *afferent* impulses from two sources. (1) Many of the long ascending fibres of the posterior funiculus give off collaterals which form synaptic connexions with the cells of the thoracic nucleus. (2) Terminals of the intermediate ascending fibres of the posterior column may behave in the same way, especially in the thoracic segments of the spinal medulla. It is uncertain which of these two sources preponderates in the formation of the posterior spinocerebellar tract.

(b) The *anterior spinocerebellar tract*, as seen on transverse section, is a crescentic, flattened tract which occupies the periphery of the lateral funiculus, in front of the area occupied by the posterior spinocerebellar tract. The precise origin of its con-

* J. F. Fulton and D. Sheehan, *J. Anat.*, Lond., 69, 1935.

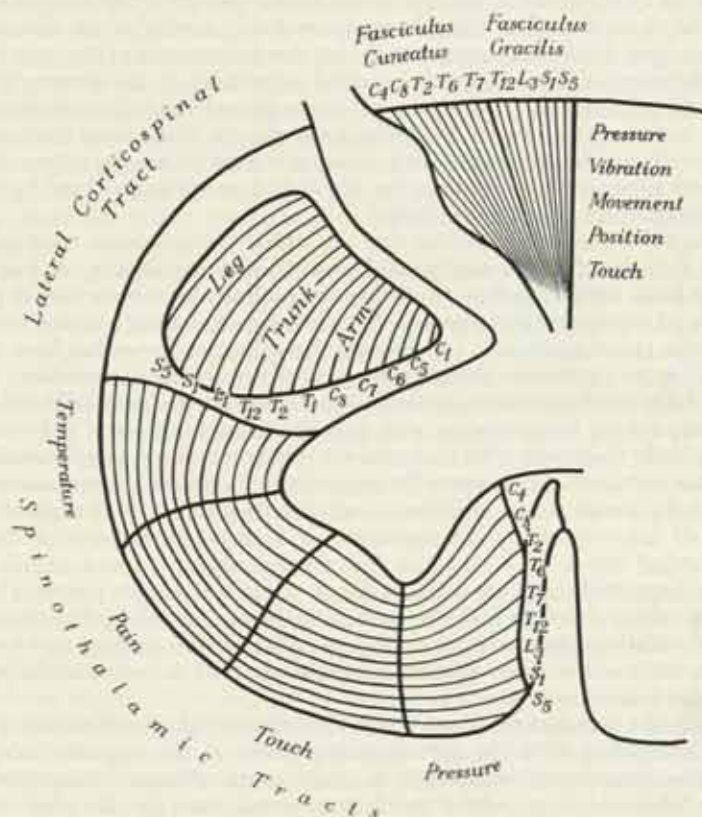
† According to some authorities this tract arises in the superior colliculus of the same side. See footnote *, p. 941.

‡ A. T. Rasmussen, *J. Comp. Neur.*, 63, 1936.

stituent fibres cannot be regarded as settled, but they are believed to arise in the large cells of the posterior grey column. They are therefore secondary neurones on the spinocerebellar pathway. The primary neurones concerned are probably similar with those described above in connexion with the posterior spinocerebellar tract, but the secondary neurones are mostly derived from the opposite side of the spinal medulla, only a small proportion ascending on the homolateral side.* The tract commences in the upper lumbar region and extends upwards to the upper part of the pons, where it turns downwards and backwards in the superior cerebellar peduncle to reach the cerebellum.

The fibres in the spinocerebellar tracts have a laminated arrangement with those carrying impulses from the lower limb being placed most superficially. They

FIG. 821.—Diagram to illustrate the segmental organisation of the fibres in the posterior funiculus, the lateral corticospinal tract and the lateral and anterior spinothalamic tracts. The cross-sectional areas of these tracts are considerably enlarged to provide adequate space. After O. Foerster. (Reproduced by kind permission of J. Springer, Berlin.)



convey to the cerebellum impulses arising in the locomotor apparatus and essential for the adjustments of muscle tonus and for synergic control during the performance of voluntary movements. As already stated (p. 938), the dorsal nucleus diminishes in size as it is traced upwards and does not extend higher than the first thoracic or last cervical segments. It would appear, therefore, that the posterior spinocerebellar tracts are concerned chiefly with the trunk and lower limbs, and evidence has been adduced† to show that the corresponding proprioceptive impulses from the upper limbs travel by the dorsal external arcuate fibres in the medulla oblongata (p. 961).

(c) The *lateral spino-thalamic tract*, which lies medial to the anterior spinocerebellar tract in the lateral funiculus of the spinal medulla is an exteroceptive

* J. Jansen and A. Brodal, *Aspects of Cerebellar Anatomy*, Oslo, 1954.

† A. Ferraro and S. E. Barrera, *Arch. Neurol. Psychiat.*, Chicago, 33, 1935.

pathway conveying *painful and thermal sensibility from the opposite side of the body*. The cell bodies of the *first neurones* on this pathway lie in the spinal ganglia and their central processes, which are unmyelinated, or only finely myelinated, enter the spinal medulla as the lateral group of the fibres of the dorsal roots (p. 940). They ascend for a very short distance—one segment or less—in the dorsolateral tract (p. 945) and then enter the substantia gelatinosa, in which they terminate by forming synaptic connexions with its nerve-cells. The *second neurone* fibres run forwards and medially, traverse the white commissure and gain the lateral funiculus of the opposite side where their fibres turn upwards in the tract, which ascends to the brain-stem in intimate relation throughout with the anterior spinocerebellar and the spinotectal tracts (fig. 817). Finally, having traversed the brain-stem and the subthalamia region they end in the ventral nucleus of the thalamus (p. 1002). There is clinical evidence which suggests that a few of the fibres take origin in the substantia gelatinosa of the *same* side.

The fibres of the anterior and lateral spinothalamic tracts show a *laminated* arrangement, those derived from the sacral segments being placed nearest to the surface of the spinal medulla, those from the lumbar segments adjoining them on the medial side, those from the thoracic segments being medial to the lumbar fibres, while those from the cervical segments occupy the deepest part of the tract (fig. 821). This arrangement is of considerable practical importance to the neurosurgeon, and it is maintained throughout the passage of the lateral tract through the medulla oblongata and the pons. In the midbrain, however, the fibres from the lower limbs extend dorsally and in this part of their course it is possible for the surgeon to divide the pain and temperature fibres from the upper limb and trunk without injury to the corresponding fibres of the lower limb.*

Although it is generally accepted that the lateral spinothalamic tract is the predominant pathway for somatic painful and thermal sensibility, it has not infrequently been suggested that an alternative pathway may exist and is provided by a series of intersegmental fibres with their neuronal bodies situated in the grey matter of the spinal medulla. In addition, the spinotectal tract has been regarded by others† as an alternative pathway for painful and thermal sensibility.

Little definite information is available concerning the pathway followed by painful impulses arising in connexion with pathological conditions of the viscera. It has been clearly shown that the first neurone fibres travel in the splanchnic nerves and it seems certain that they enter the spinal medulla via the white rami communicantes and the dorsal roots. Whatever pathway they follow in the spinal medulla they are all interrupted by the operation of bilateral cordotomy of the lateral funiculi carried out at the level of the first thoracic segment,‡ and on this account it has been suggested that they travel in the lateral spinothalamic tract. The reader should note that, although hitherto defined as being formed by the union of the lateral and anterior spinothalamic tracts, the *spinal lemniscus* may now be defined more accurately as the *direct upward continuation of the lateral spinothalamic tract only* into the brain-stem (p. 958).

Owing to the fact that the fibres which form the lateral spinothalamic tract cross at once, decussating with the corresponding fibres of the opposite side, lesions affecting the commissural area, such as occur in the disease, *syringomyelia*, will produce a bilateral loss of painful and thermal sensibilities for the particular areas involved.

(d) The *spinotectal tract* is placed medial to the anterior spinocerebellar tract and anterior to the lateral spinothalamic tract, the three tracts being intimately related topographically throughout their ascending course in the spinal medulla and brain-stem. Its constituent fibres arise in the posterior grey column of the opposite side and soon cross the median plane to reach the lateral funiculus. They ascend to the mid-brain where they terminate in the superior colliculus of the tectum. They provide an ascending pathway for spinovisual reflexes. In this connexion it is to be remembered that the superior colliculi constitute a reflex centre on the visual path and are not concerned with the transmission of visual impulses to the cerebral cortex. Afferent impulses passing up the spinotectal tract result in movements of the head and eyes towards the source of stimulation.

* A. Earl Walker, *Arch. Neurol. Psychiat.*, 48, 1942.

† A. Earl Walker, *Assoc. Res. Nerv. Ment. Dis.*, 23, 1943.

‡ O. R. Hyndman and J. Wolkin, *Arch. Neurol. Psychiat.*, 50, 1943.

(e) The *dorsolateral tract* is a small strand situated at the tip of the posterior grey column, close to the entrance of the dorsal roots. It consists of unmyelinated and finely myelinated fibres which do not receive their medullary sheaths until near the close of foetal life. It is usually regarded as being formed by the lateral group of the fibres of the dorsal roots, which ascend for a short distance in the tract and then enter the substantia gelatinosa, where new fibres arise and pass to the lateral spinothalamic tract of the opposite side. From what has already been stated, it may be inferred that the dorsolateral tract is formed by the fibres which convey painful and thermal sensibilities in the spinal nerves.

3. **Intersegmental tracts.**—The *lateral intersegmental tract* constitutes the remainder of the lateral funiculus, and is continuous in front with the anterior intersegmental tract. It consists chiefly of intersegmental fibres which arise from cells in the grey matter, and, after a longer or shorter course, re-enter the grey matter and ramify in it. Most of the fibres of the anterior and lateral intersegmental tracts are confined to the same side but some cross to the opposite side of the spinal medulla. They include fibres of the *reticulospinal tract* (p. 954). This tract consists of a series of relays for impulses which originate in the reticular formation of the brain stem and terminate in connexion with the motor cells of the anterior column of the grey matter. Some of the fibres of the lateral intersegmental tract are ascending and are continued upwards into the brain as constituents of the *medial longitudinal bundle*. It has been suggested that this intersegmental tract may function as an alternative route for exteroceptive sensibility.

Tracts in the posterior funiculus.—1. Ascending tracts.

This funiculus comprises two large tracts, viz. the *fasciculus gracilis* and the *fasciculus cuneatus*, which are separated from each other by the postero-intermediate septum.

The *fasciculus gracilis* commences at the lowest limit of the spinal medulla and is composed mainly of the ascending branches of the medial bundle of fibres of the dorsal nerve-roots. They run upwards in the posterior funiculus, and as the tract ascends it receives accessions from each dorsal root. The fibres which enter in the coccygeal and lower sacral regions are thrust medially by the fibres which enter at a higher level. The *fasciculus gracilis*, which contains fibres derived from the lower thoracic, lumbar, sacral and coccygeal segments, occupies the medial part of the posterior funiculus in the upper part of the spinal medulla (fig. 821). The *fasciculus cuneatus* commences in the mid-thoracic region and derives its fibres from the dorsal roots of the upper thoracic and cervical nerves and, in consequence, is placed on the lateral side of the *fasciculus gracilis* (figs. 821 and 822).

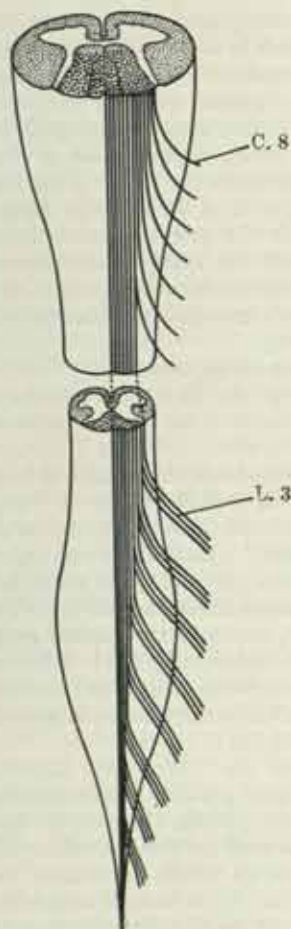
Both fasciculi are heavily myelinated, and the fibres are larger in the *fasciculus cuneatus* than they are in the *fasciculus gracilis*. Both fasciculi contain the central processes from cells in the spinal ganglia, i.e. receptor neurones, and these pass without interruption and uncrossed to the medulla oblongata, where they end in the gracile and cuneate nuclei, in which the second neurones of this pathway begin. The majority of the fibres of the second neurones sweep ventrally round the central grey matter (fig. 829), as the *internal arcuate fibres*, and take part in the decussation of the lemnisci. Thereafter, as the *medial lemnisci*, they ascend on each side to the ventral nucleus of the thalamus (p. 1002) and are there relayed to the cortex of the post-central gyrus. Through the medium of the *posterior external arcuate fibres* (p. 958) the remaining fibres of the posterior funiculus are relayed to the cerebellum.

These two tracts, which occupy nearly the whole of the posterior funiculus convey elements of tactile and of deep sensibility, with the possible exception of pressure and pressure pain. The fibres concerned all pass up to the medulla oblongata uncrossed in the posterior funiculi, together with the fibres which convey sensations of posture and of movements, both active and passive. It is interesting to observe that the exteroceptive pathways of the lateral and anterior funiculi are phylogenetically older than the proprioceptive and tactile pathway of the posterior funiculus.

2. **Descending tracts.**—The posterior funiculus contains some descending fibres, which occupy different positions at different levels (figs. 817, 823). In the cervical and upper thoracic regions they appear in transverse section as a comma-shaped fasciculus, termed the *semilunar tract*, in the medial part of the *fasciculus cuneatus*, the blunt end of the fasciculus being directed forwards. In the lower

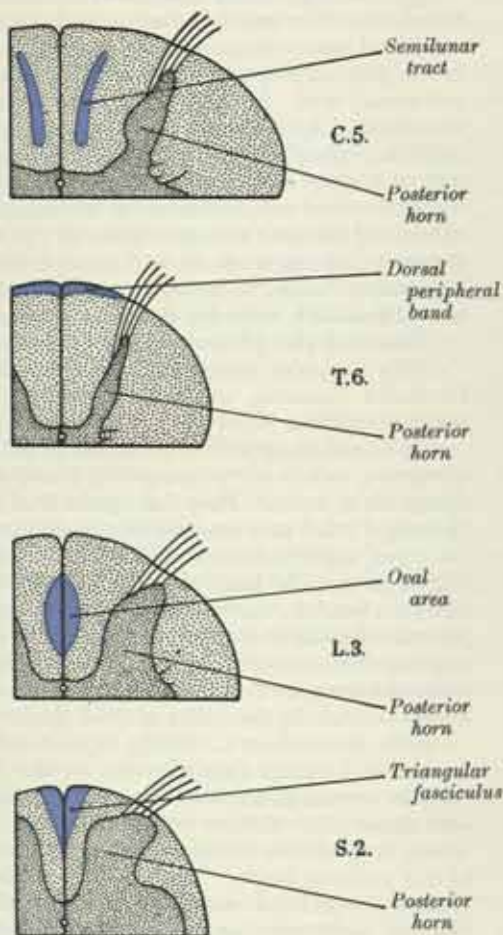
thoracic region they form a *dorsal peripheral strand* on the posterior surface of the spinal medulla; in the lumbar region they are situated by the side of the posterior median septum, and appear on transverse section as a semi-oval bundle; in the conus medullaris they assume the form of a *triangular strand* in the posteromedial part of the fasciculus gracilis. Collectively these three strands constitute the *septo-*

FIG. 822.—A diagram showing the lamination of the fibres in the posterior funiculus. (After Poirier.)



The spinal medulla viewed from behind. The drawing shows that the posterior funiculus is formed by the long ascending fibres of the dorsal roots and that the sacral nerves lie next the median plane, the lumbar to their lateral side, the thoracic more laterally, and the cervical most lateral of all.

FIG. 823.—The descending fibres in the posterior funiculi, shown at different levels. (After Testut.)



marginal tract. These descending fibres in the posterior funiculus are mainly intersegmental in character and derived from cells in the posterior grey column, but some are said to consist of the descending branches of the dorsal nerve-roots (*vide infra*). The semilunar tract was supposed to belong to the second category, but against this view is the fact that it does not undergo descending degeneration when the dorsal nerve-roots are destroyed.

3. **Intersegmental tracts.**—Occupying the anterior or deepest part of the posterior funiculus is a small strand of fibres named the *posterior intersegmental tract*. It is somewhat crescentic on transverse section, and is placed just behind the grey commissure (fig. 817); it is best marked in the lumbar region, but can be traced into the thoracic and cervical regions. Its fibres, which are intersegmental, are derived from the cells of the posterior grey column; they divide into ascending and descending branches which re-enter and ramify in the grey matter.

It should be stated that fibres which are a constituent part of the extrapyramidal side of the motor system (p. 1076) arise from the grey matter of the tegmentum of the mid-brain and the reticular formation of the pons and medulla oblongata and descend in the spinal medulla both as ipsilateral and as contralateral fibres. The position of these tementospinal and reticulospinal fibres in the spinal medulla has not yet been identified with certainty, but the latter are believed to travel in the lateral intersegmental tract (p. 945).

RECOGNITION OF DIFFERENT REGIONS OF THE SPINAL MEDULLA IN TRANSVERSE SECTIONS (fig. 815)

(1) *Cervical region.*—The section is large and oval in shape. The white matter is present in greater amount than in any other region, because the ascending tracts have collected many fibres at lower levels and the descending tracts have not yet lost many fibres. The grey matter is greatly increased in the cervical enlargement, where the nerves of the brachial plexus arise. Because of the relatively large amount of white matter, however, the grey matter at this level does not appear to be disproportionately increased. The increase affects particularly the anterior horn, which is very wide, the posterior horn being long and slender. The grey commissure is nearer the anterior surface than the posterior surface.

(2) *Thoracic region.*—The section is small and almost circular in outline. Both anterior and posterior horns of the grey matter are very slender and the intermedio-lateral group of cells produces a *lateral horn*.

(3) *Lumbar region.*—The section is larger than in the thoracic region and the enlargement affects only the grey matter, the white matter being less in amount, as fewer fibres have joined the ascending tracts at this level and more have left the descending tracts. Both anterior and posterior horns of grey matter are very wide and the grey matter is disproportionately large in amount. A lateral horn is present opposite the upper one or two lumbar nerves. The grey commissure is about equidistant from the anterior and posterior surfaces.

(4) *Sacral region.*—In the conus medullaris the grey matter assumes the form of two oval masses, one in each half of the spinal medulla, connected together by a broad grey commissure. White matter is very small in amount and the whole section is smaller than in any other region.

THE RHOMBENCEPHALON OR HIND BRAIN

The rhombencephalon comprises the medulla oblongata, pons and cerebellum; its cavity is the fourth ventricle. The medulla oblongata and pons are traversed by fibre tracts which inter-connect these and other parts of the central nervous system and contain, amongst others, collections of nerve cells which constitute the nuclei of several of the cranial nerves. The following cranial nerves have their superficial origins from the pons and medulla oblongata: trigeminal, abducent, facial, stato-acoustic, glossopharyngeal, vagus, cranial roots of the accessory and hypoglossal. Scattered among the nuclei and tracts is the reticular formation which consists of intermingled grey and white matter, the precise connexions of which are at present uncertain. The medulla oblongata and pons also contain centres concerned with:

- (1) the control of the heart and respiratory apparatus
- (2) the control of the alimentary tract and its derivatives
- and (3) the vestibular and auditory apparatuses.

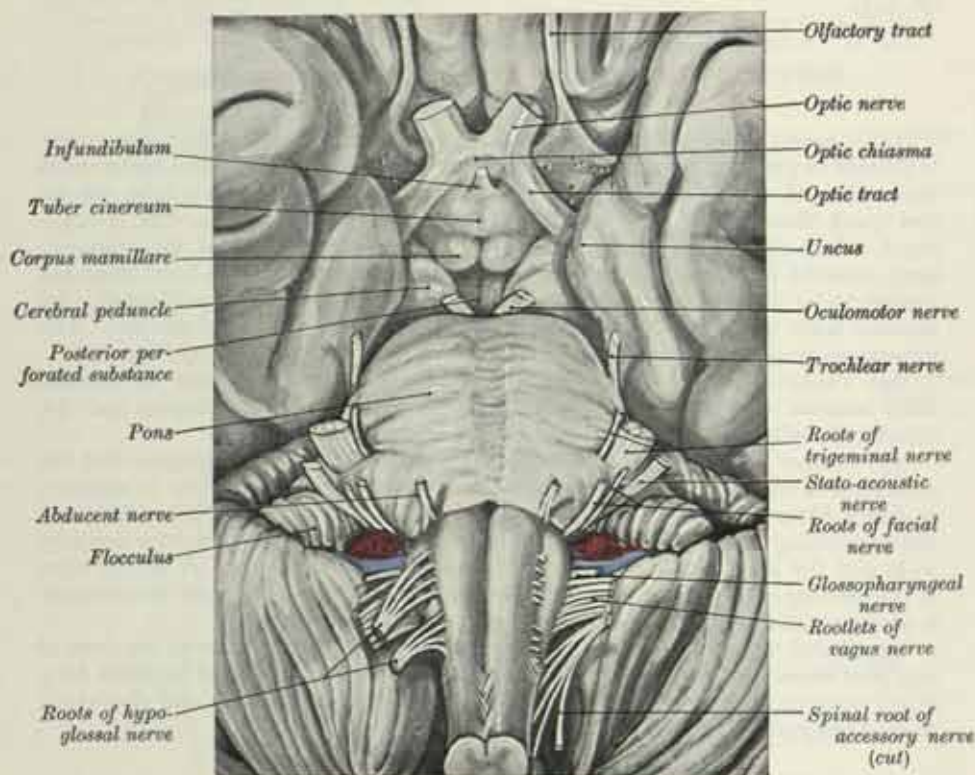
THE MEDULLA OBLONGATA

The **medulla oblongata** extends from the lower margin of the pons to a transverse plane passing above the first pair of cervical nerves; this plane corresponds with the upper border of the atlas behind, and the middle of the dens of the axis in front; at this level the medulla oblongata is continuous with the spinal medulla. The anterior surface of the medulla oblongata is separated from the basilar part of the occipital bone and the upper part of the dens by the membranes of the brain, and the occipito-axial ligaments. Posteriorly it is received into the notch between

the hemispheres of the cerebellum, and the upper portion of this surface forms the lower part of the floor of the fourth ventricle.

The medulla oblongata is somewhat piriform in shape (fig. 824), its broad extremity being directed upwards towards the pons, while its narrow lower end is

FIG. 824.—The ventral aspect of the brain-stem and the interpeduncular fossa.



The wall of the lateral recess of the fourth ventricle is shown in blue, and the chorioid plexus, which protrudes through the foramen of the lateral recess into the subarachnoid space, is coloured crimson.

Note that the lateral recess covers the medial part of the flocculus and is itself partially obscured by the rootlets of the glossopharyngeal nerve.

continuous with the spinal medulla. It measures about 3 cm. longitudinally, 2 cm. transversely at its widest part, and 1.25 cm. anteroposteriorly. The central canal of the spinal medulla is prolonged into its lower half, and then opens into the cavity of the fourth ventricle; the medulla oblongata may therefore be divided into a lower, closed part containing the central canal, and an upper, open part corresponding with the lower portion of the fourth ventricle. Its anterior and posterior surfaces are marked by median fissures.

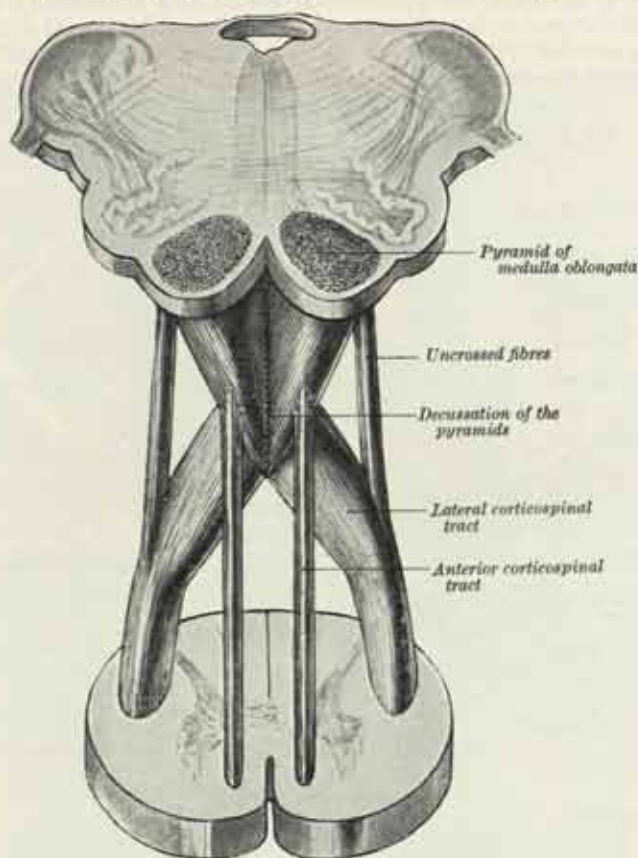
The **anterior median fissure** contains a short fold of pia mater, and extends along the entire length of the medulla oblongata; below, it is continuous with the anterior median fissure of the spinal medulla; above, it ends at the lower border of the pons in a small triangular expansion termed the *foramen cæcum*. Its lower part is interrupted by bundles of fibres which cross obliquely from one side to the other, and constitute the *decussation of the pyramids*. Some fibres, termed the *anterior external arcuate fibres*, emerge from the fissure above this decussation and curve laterally over the surface of the medulla oblongata.

The **posterior median sulcus** is a narrow groove which exists only in the closed part of the medulla oblongata; it is continuous below with the posterior median sulcus of the spinal medulla, but becomes rapidly shallower from below upwards, and ends about the middle of the medulla oblongata, where the central canal expands into the cavity of the fourth ventricle.

Certain of the cranial nerves pass through the substance of the medulla oblongata and are attached to its surface in series with the roots of the spinal nerves. The

fibres of the hypoglossal nerve correspond in position with the ventral roots of the spinal nerves and emerge in linear series from a furrow termed the *anterolateral sulcus*. Similarly, the accessory, vagus, and glossopharyngeal nerves are in line with the dorsal roots of the spinal nerves (p. 1144) and are attached to the bottom of a sulcus named the *posterolateral sulcus*. Advantage is taken of this arrangement to

FIG. 825.—A scheme showing the decussation of the pyramids.



subdivide each half of the medulla oblongata into anterior, middle and posterior regions. Although these three regions appear to be directly continuous with the corresponding funiculi of the spinal medulla they do not contain precisely the same nerve-fibres, since some of the fasciculi of the spinal medulla end in the medulla oblongata, while others alter their course in passing through it.

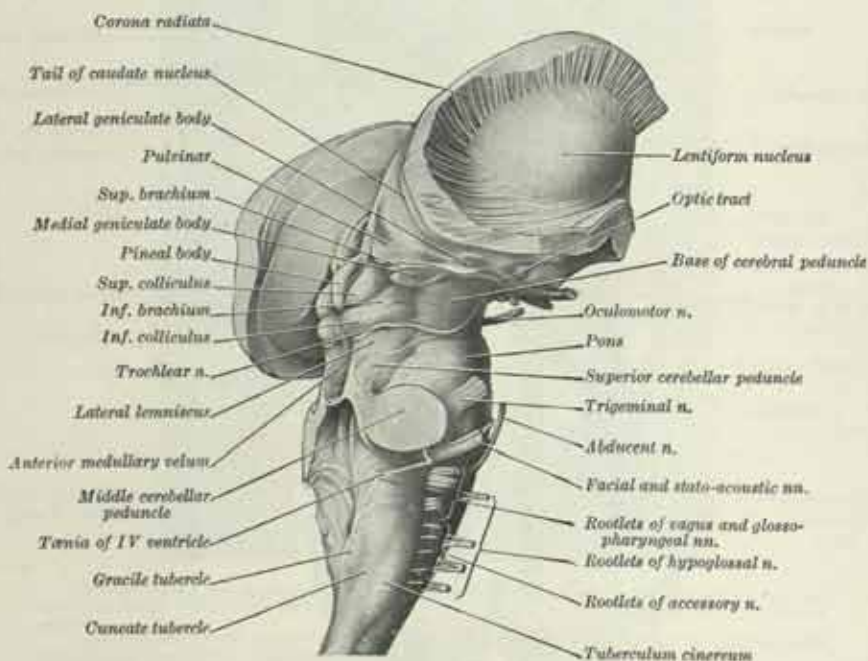
The **anterior region** of the medulla oblongata (fig. 824) lies between the anterior median fissure and the anterolateral sulcus, forming a surface elevation which is named the *pyramid*. Its upper end is slightly constricted and between it and the pons the fibres of the abducent nerve emerge; below, it tapers into the anterior funiculus of the spinal medulla, with which it appears to be directly continuous.

The two pyramids contain the motor fibres which pass from the brain to the spinal medulla. When traced downwards, two-thirds or more of these fibres leave the pyramids in successive bundles, and decussate in the anterior median fissure, forming what is termed the *decussation of the pyramids*. Having crossed the median plane, they pass down in the posterior part of the lateral funiculus of the spinal medulla as the lateral corticospinal tract. The remaining fibres—i.e. those in the lateral part of the pyramid—do not cross the median plane; some descend as the anterior corticospinal tract (fig. 825) into the anterior funiculus of the same side of the spinal medulla, while others incline backwards and laterally to join the lateral corticospinal tract of the same side (p. 942).

The **lateral region** of the medulla oblongata (fig. 826) is limited in front by the

anterolateral sulcus and the roots of the hypoglossal nerve, and behind by the posterolateral sulcus and the roots of the glossopharyngeal, vagus, and accessory nerves. Its upper part consists of a prominent oval mass which is named the *olive*, while its lower part is of the same width as the lateral funiculus of the spinal medulla, and appears on the surface to be a direct continuation of it. As a matter of fact, only a portion of the lateral funiculus of the spinal medulla is continued upwards into this region, for the lateral corticospinal tract is derived from the pyramid of the opposite side and most of the fibres of the posterior spinocerebellar tract leave it to enter the inferior cerebellar peduncle in the posterior region. The lateral intersegmental tract and the anterior spinocerebellar tract are continued upwards into the lateral region of the medulla oblongata.

FIG. 826.—The hind-brain and mid-brain, viewed from the posterolateral aspect.



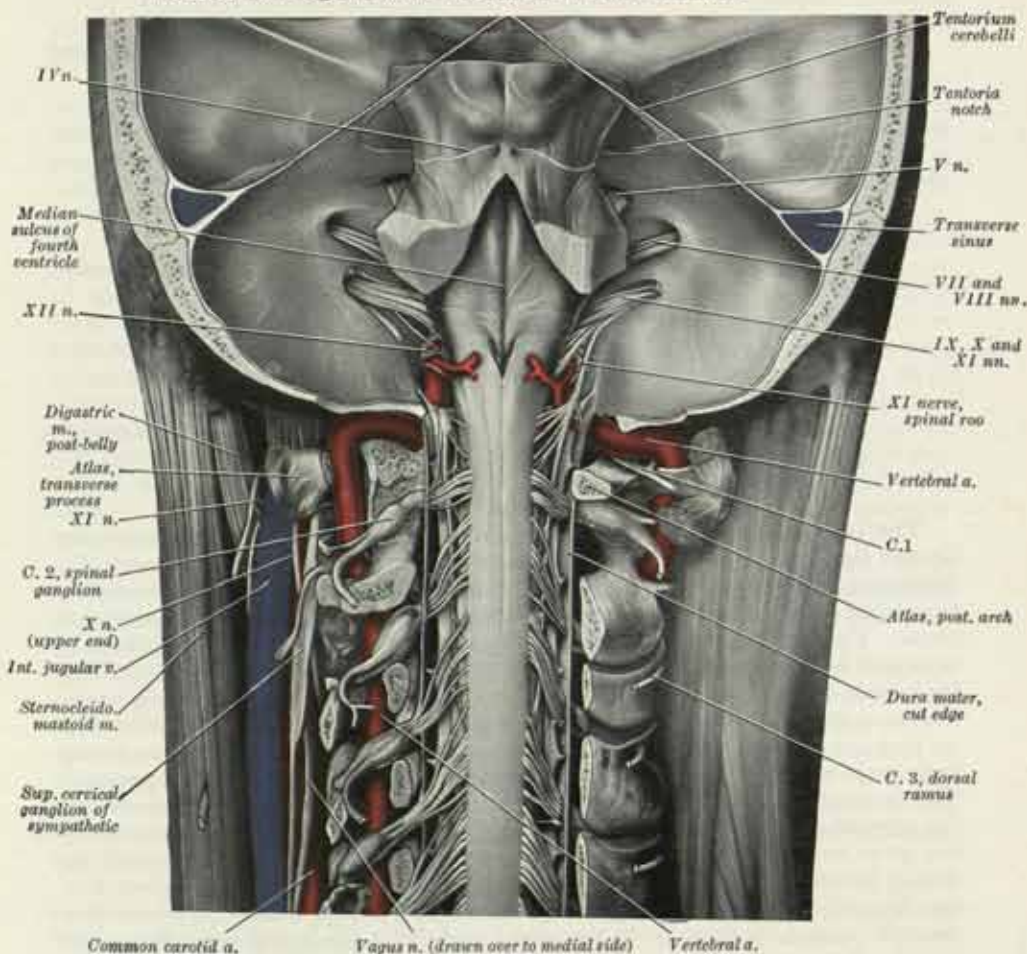
The **olive** is a smooth, oval elevation, which is caused by an underlying nucleus of grey matter named the *olivary nucleus* (p. 956). It is situated lateral to the pyramid, from which it is separated by the anterolateral sulcus and the fibres of the hypoglossal nerve. Behind, it is separated from the posterolateral sulcus by the small superficial strand of the anterior spinocerebellar tract. It is about 1.25 cm. long, and dorsilateral to its upper end there is a slight depression at the lower border of the pons to which the roots of the facial nerve are attached. The anterior external arcuate fibres emerge from the anterior median fissure, and wind backwards across the pyramid and the olive to enter the inferior cerebellar peduncle (fig. 835).

The **posterior region** of the medulla oblongata (figs. 826, 827) lies behind the posterolateral sulcus and the roots of the accessory, vagus and glossopharyngeal nerves, and, like the lateral region, is divisible into a lower and an upper portion.

The **lower part** is limited behind by the posterior median sulcus, and consists of the upward continuation of the *fasciculus gracilis* and the *fasciculus cuneatus* of the spinal medulla. The fasciculus gracilis is placed along the side of the posterior median sulcus, and is separated from the fasciculus cuneatus by a faint longitudinal groove and a septum. These two fasciculi are at first vertical; but at the lower part of the fourth ventricle they diverge from the median plane, and each presents an elongated swelling. The swelling on the fasciculus gracilis is named the *gracile tubercle*, and is produced by the upper end of a subjacent nucleus of grey matter termed the *nucleus gracilis*; that on the fasciculus cuneatus is termed the *cuneate*

tubercle, and is caused similarly by a nucleus named the *nucleus cuneatus*. The fibres of these two fasciculi end by forming synapses with the cells in their respective nuclei. A third elevation (often termed the *tuberculum cinereum*) can sometimes be recognised in the lower part of the posterior region of the medulla oblongata (fig. 826). It lies between the fasciculus cuneatus and the roots of the accessory nerve, and is narrow below but wider above. It is produced by a nucleus which is con-

FIG. 827.—A dissection exposing the brain-stem and the upper part of the spinal medulla after removal of large portions of the occipital and parietal bones, and the cerebellum together with the roof of the fourth ventricle.



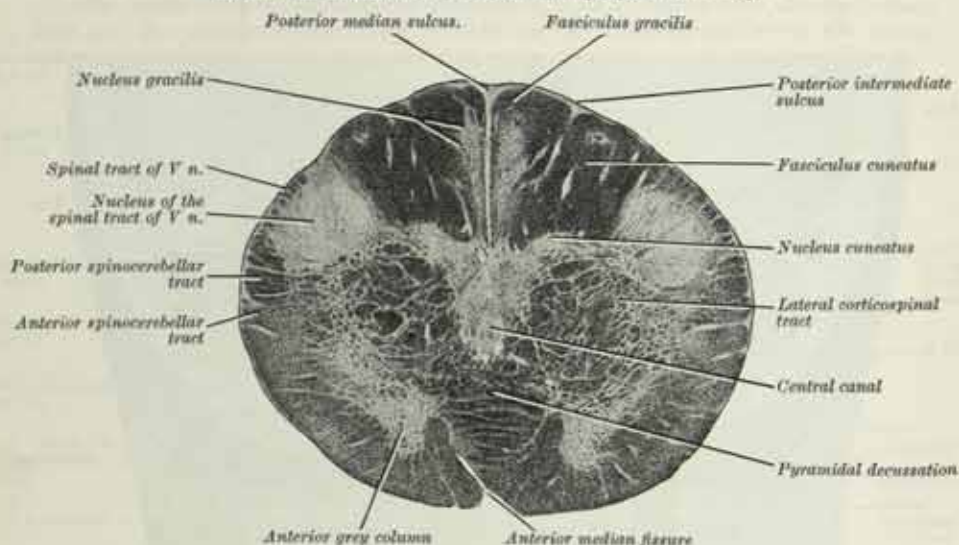
Note.—On the left side the foramina transversaria of the atlas and the third, fourth and fifth cervical vertebrae have been opened to expose the vertebral artery. On the right side the posterior arch of the atlas and the laminae of the succeeding cervical vertebrae have been divided and have been removed together with the vertebral spines and the laminae of the opposite side. The tentorium cerebelli and the transverse sinuses have been divided and their posterior portions removed.

tinuous below with the substantia gelatinosa, and in which the fibres of the spinal tract of the trigeminal nerve end; these fibres separate the nucleus from the surface of the medulla oblongata (p. 953). The *obex* and the *tæniæ of the fourth ventricle* are described on p. 985.

The *upper part* of the posterior region of the medulla oblongata is occupied by the *inferior cerebellar peduncle*, a thick rope-like strand situated between the lower part of the fourth ventricle and the roots of the glossopharyngeal and vagus nerves. The two inferior cerebellar peduncles leave the dorsolateral aspect of the medulla oblongata and pass to the cerebellum. As they ascend, they diverge from each other, and assist in forming the lower parts of the lateral boundaries of the fourth ventricle; higher up, they are directed backwards, each passing to the corresponding cerebellar hemisphere. Near their entrance into the cerebellum they are crossed by several

strands of fibres which run to the median sulcus of the floor, or anterior wall, of the fourth ventricle and are named the *striae medullares* (fig. 853). The inferior cerebellar peduncle is not the upward continuation of the fasciculus gracilis and fasciculus cuneatus, although it appears to be so, for the fibres of these fasciculi end in the nucleus gracilis and nucleus cuneatus. The constitution of the inferior cerebellar peduncle is described on pp. 960 and 961.

FIG. 828.—Transverse section through the medulla oblongata at the level of the pyramidal decussation. Weigert Pal preparation. $\times 7$.



The internal structure of the medulla oblongata.—(1) *A transverse section through the lower part of the medulla oblongata* shows many of the appearances of a transverse section through the upper end of the spinal medulla. The posterior, lateral and anterior funiculi can be identified easily, and they contain the same nerve tracts. The grey matter shows two very striking alterations. The anterior horn is separated from the central grey matter by the pyramidal fibres, which are coursing backwards and laterally to reach the lateral funiculus of the opposite side. In the upper part of the medulla oblongata the pyramidal fibres occupy its ventrimedial portion, but in the lower part the majority of them cross the median plane, inclining backwards, as they do so (fig. 825) and decussating in front of the central grey matter. The decussation takes place in an orderly manner with the fibres which terminate in the cervical segments of the spinal medulla decussating first. The decussation of the great motor tracts [*decussation of the pyramids*] constitutes the most striking feature in sections of the medulla oblongata at this level. The actual proportion of the fibres which take part is subject to variation, but, as a rule, about 70 per cent. of them do so and continue down the spinal medulla in the lateral funiculus as the lateral, or crossed, corticospinal (pyramidal) tract. Of the remaining fibres some retain their ventrimedial position and descend in the anterior funiculus of the spinal medulla as the anterior corticospinal tract; others descend with the crossed fibres in the lateral funiculus of the same side (p. 942). As a result of this decussation the anterior intersegmental tract of the spinal medulla is thrust backwards towards the central grey matter, which also takes up a more dorsal position so that the central canal inclines backwards as it ascends. The continuity between the anterior grey column and the central grey matter, maintained throughout the whole length of the spinal medulla, is severed. At higher levels the detached anterior column rapidly diminishes in size and merges into the grey matter of the *formatio reticularis* (p. 954); at this level it is termed the *supraspinal nucleus*, and gives origin to the spinal part of the accessory nerve.

The outline of the posterior horn of the grey matter can still be made out, but it, too, has undergone some modification. A narrow, strip-like portion of grey matter appears in the heart of the fasciculus gracilis, continuous ventrally with the base of the posterior horn. This constitutes the lower end of the *nucleus gracilis*, which extends upwards as far as the lower limit of the fourth ventricle and forms an eleva-

tion on the posterior surface of the medulla oblongata, already described as the gracile tubercle (p. 951). A second wedge-shaped projection from the base of the posterior horn, beginning at a slightly higher level, invades the ventral part of the fasciculus cuneatus, and constitutes the *nucleus cuneatus*.

The *substantia gelatinosa* is a prominent feature, and is a direct upward continuation of that in the spinal medulla. In this situation it constitutes the lower end of the *nucleus of the spinal tract of the trigeminal nerve*, and the fibres of the tract itself are interposed between the nucleus and the surface of the medulla oblongata (fig. 828). It will be considered in detail in a subsequent section (p. 966).

(2) *A transverse section made just above the decussation of the pyramids* shows an accentuation of the differences already noted and the appearance of certain new elements (fig. 829).

The *nucleus gracilis* has increased in breadth and the fibres of its corresponding fasciculus are grouped together on its dorsal, medial and lateral surfaces; the *nucleus cuneatus* has undergone a similar change. At first both retain their continuity with the central grey matter, but this is lost at higher levels. The fibres of the fasciculus gracilis and cuneatus have ascended uncrossed through the spinal medulla, and they terminate in their respective nuclei at different levels by forming synapses with their contained nerve-cells. New fibres arise in the nuclei and constitute the second neurones on the pathway of tactile and proprioceptive sensibilities. The *internal arcuate fibres* emerge from the ventral aspects of the nuclei and, curving forwards and laterally at first round the central grey matter, they bend medially to reach the median plane, where they decussate with the corresponding fibres of the opposite side (fig. 824). Thereafter, they turn upwards and ascend on the opposite side close to the median raphe, constituting the *medial lemniscus*. The *decussation of the lemnisci* occurs in the area dorsal to the pyramids and in front of the central grey matter, which is in this way thrust still further backwards towards the dorsal surface of the medulla oblongata. As the internal arcuate fibres sweep forwards they sever the continuity between the *substantia gelatinosa* and the central grey matter.

The *accessory cuneate nucleus*, lies dorsolateral to the cuneate nucleus. It is composed of large cells similar to those of the dorsal nucleus of the spinal medulla and gives origin to the *posterior external arcuate fibres* (pp. 958 and 961), which are destined for the cerebellum.

The *nucleus of the spinal tract of the trigeminal nerve* is now severed from the central grey matter by the internal arcuate fibres. It is separated from the lateral surface of the medulla oblongata only by the fibres whose terminal nucleus it constitutes and by some of the fibres of the posterior spinocerebellar tract which is beginning to incline dorsally to enter the inferior cerebellar peduncle. It is in this part of its course that the spinal tract of the trigeminal nerve lies nearest to the surface of the brain-stem (fig. 829) and its fibres can be divided with the minimum risk of damage to adjoining structures.*

Two additional collections of grey matter are found at this level. One lies dorsal to the lateral part of the pyramid, while the other is placed to its medial side and not far from the median plane. These are portions of the *medial accessory olivary nucleus* and will be considered together with the olivary nucleus.

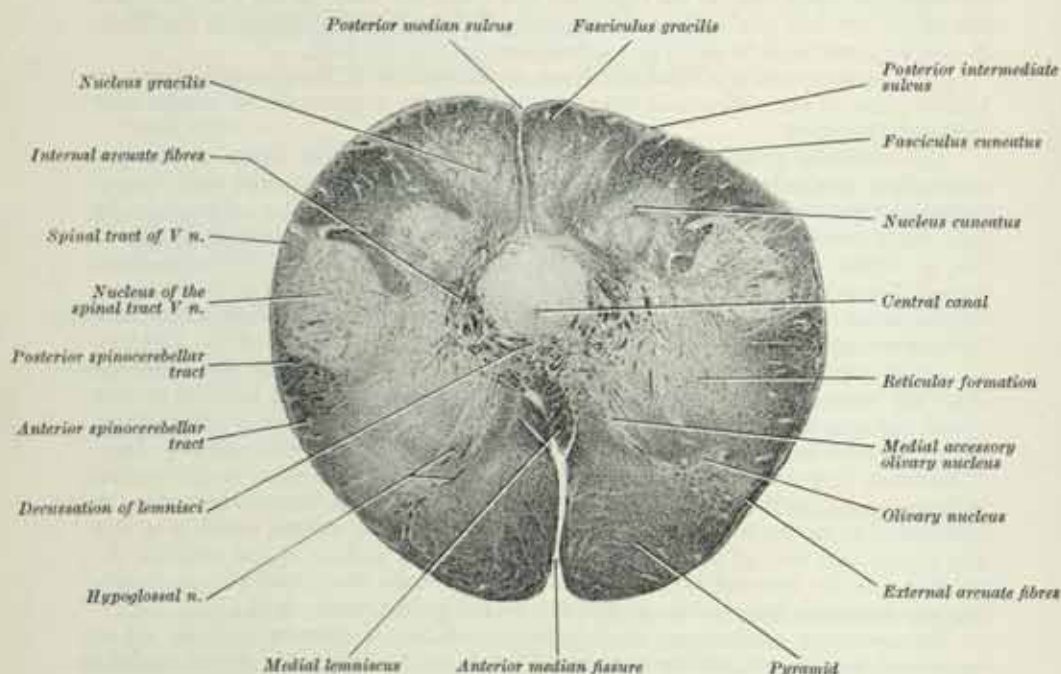
The central grey matter, now occupying a position near the dorsal surface of the medulla oblongata, contains three important nuclei. A prominent group of large motor nerve-cells is situated ventrimedially. This is the *nucleus of the hypoglossal nerve*. It extends upwards into the open part of the medulla oblongata where it lies under the medial part of the trigonum hypoglossi in the floor of the fourth ventricle. Dorsolateral to the hypoglossal nucleus, there is a second group of cells, which constitutes the *dorsal nucleus of the vagus*. It is a mixed nucleus, containing cells of two different types. The larger cells give rise to the fine fibres which innervate unstriated muscle, while the smaller spindle-shaped cells may possibly be concerned with visceral afferent impulses (fig. 140). On the other hand many authorities believe that all the vagal afferent fibres terminate in the nucleus of the tractus solitarius (*see below*). At a higher level the dorsal nucleus of the vagus lies to the lateral side of the hypoglossal nucleus in the floor of the fourth ventricle and corresponds in position to the trigonum vagi.

A third group of cells lies dorsolateral to the dorsal nucleus of the vagus at this

* Murray A. Falconer, *J. Neurol. Neurosurg. Psychiat.*, 12, 1949.

level. It is the *nucleus of the tractus solitarius*, and it is intimately related to a group of descending fibres which constitute the *tractus solitarius* itself. At the caudal end of the medulla oblongata these two nuclei fuse dorsal to the central canal. As the nucleus of the tractus solitarius is traced upwards it comes to lie more deeply in the

FIG. 829.—A transverse section through the medulla oblongata at the level of the decussation of the lemnisci. Weigert Pal preparation. $\times 6$.



medulla oblongata, on the ventrolateral aspect of the dorsal nucleus, with which it is practically co-extensive. The tractus solitarius receives afferent fibres from the facial, glossopharyngeal and vagus nerves, and they enter the nucleus in that order from above downwards, conveying to it gustatory sensibility from the mucous membrane of the tongue and palate (VII, IX and X), and, according to many authorities, visceral sensibility from the pharynx (IX and X) and from the œsophagus and the abdominal part of the alimentary canal (X).

In addition, numerous scattered islets of grey matter are found in the centre of the ventrolateral portion of the medulla oblongata. They occupy an area which is freely intersected by nerve-fibres running in all directions and which is therefore termed the *reticular formation*. It is present at all levels of the medulla oblongata and extends upwards into the tegmentum of the pons and midbrain. Its constituent cells appear to be arranged in groups, but these cannot be differentiated by any known histological methods and their existence has been inferred from the results of experimental work. They receive *afferent fibres* from the subthalamic nucleus (p. 1009), the substantia nigra, the red nucleus (p. 992), the fastigio-bulbar tract (p. 979) and from the descending branches of the fibres of the superior cerebellar peduncles.

Some of the cells of the reticular formation are intercalated neurones on the extrapyramidal pathway. Their axons descend to the spinal medulla as the reticulo-spinal tract, but it is uncertain whether these reticulo-spinal fibres descend by a series of relays or whether they are uninterrupted. They are both crossed and uncrossed and it has been suggested that both systems run in the anterior funiculus and that crossed fibres only descend in the lateral funiculus of the spinal medulla.* The nerve impulses transmitted by these descending fibres are believed to be carried to the muscle spindles by way of the small efferent fibres (γ efferents) which are found in motor nerves.† The cells of the reticular

* J. W. Papez, *J. comp. Neurol.*, **41**, 1926.

† R. Granit and B. Kadda, *Acta physiol. scand.*, **27**, 1953.

formation are linked with one another by a large number of closed feed-back circuits, and there is experimental evidence in favour of the view that some group or groups play an important part in the mediation of inhibition whilst others are concerned with facilitation of the activity of the anterior grey column cells.*

The white matter has undergone an important rearrangement. The *pyramidal tracts* constitute two large bundles placed in the ventral part of the section, one on each side of the anterior median fissure. Dorsally they are related to the accessory olivary nuclei and the sensory decussation.

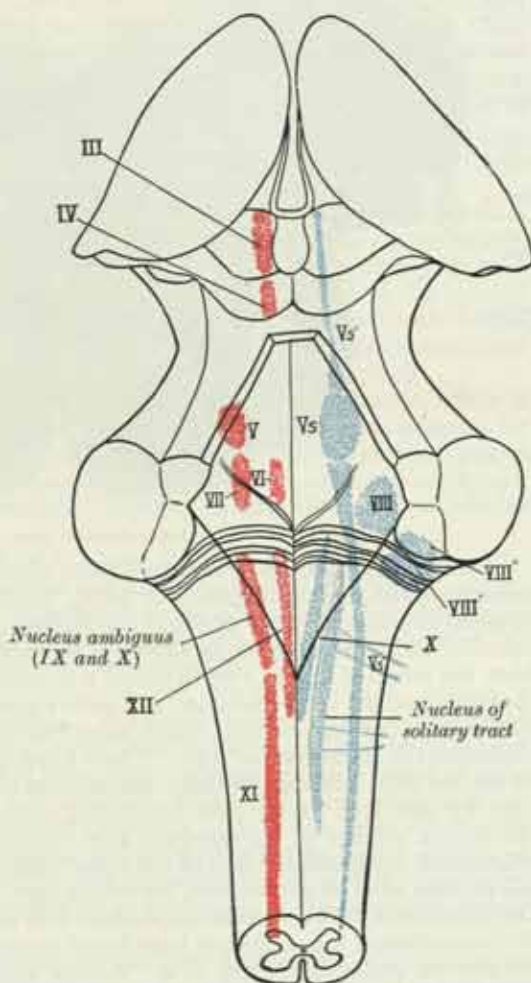
The fibres of the *medial lemniscus* (p. 953), after emerging from the decussation of the lemnisci, turn upwards abruptly in the form of a flattened tract, closely applied to the median raphe. In this position they ascend to the pons, increasing in number as additional fibres join them from the upper levels of the decussation. Ventrally they are related to the pyramidal tract, and dorsally to the medial longitudinal bundle and the tecto-spinal tract. On the lateral side of the medial lemniscus lies the grey matter of the *formatio reticularis* intersected by the internal arcuate fibres. It seems probable that in the decussation the fibres undergo a rearrangement whereby those derived from the gracile nucleus come to lie ventral to those derived from the cuneate nucleus and, at a higher level, where the disposition of the medial lemniscus in the brain-stem becomes altered (p. 967), the gracile fibres are placed laterally and the cuneate fibres medially.

The *medial longitudinal bundle* forms a small compact tract of nerve-fibres, situated close to the median plane and ventral to the hypoglossal nucleus. Below, it is continuous with the anterior intersegmental tract of the spinal medulla, but at this level it has been thrust dorsally by the decussations of the pyramids and lemnisci. It is continued upwards through the pons and the mid-brain in the same position relative to the central grey matter and the median plane, and therefore comes into intimate relationship throughout its course with the somatic efferent column of the grey matter. The constituent fibres of the tract run relatively short courses within it, for they are derived from a variety of sources, which are detailed on p. 995.

The spinocerebellar, lateral spinothalamic, spinotectal, olivospinal, vestibulospinal and rubrospinal tracts are all found in the anterolateral area, limited dorsally by the nucleus of the spinal tract of the trigeminal nerve and ventrally by the pyramid.

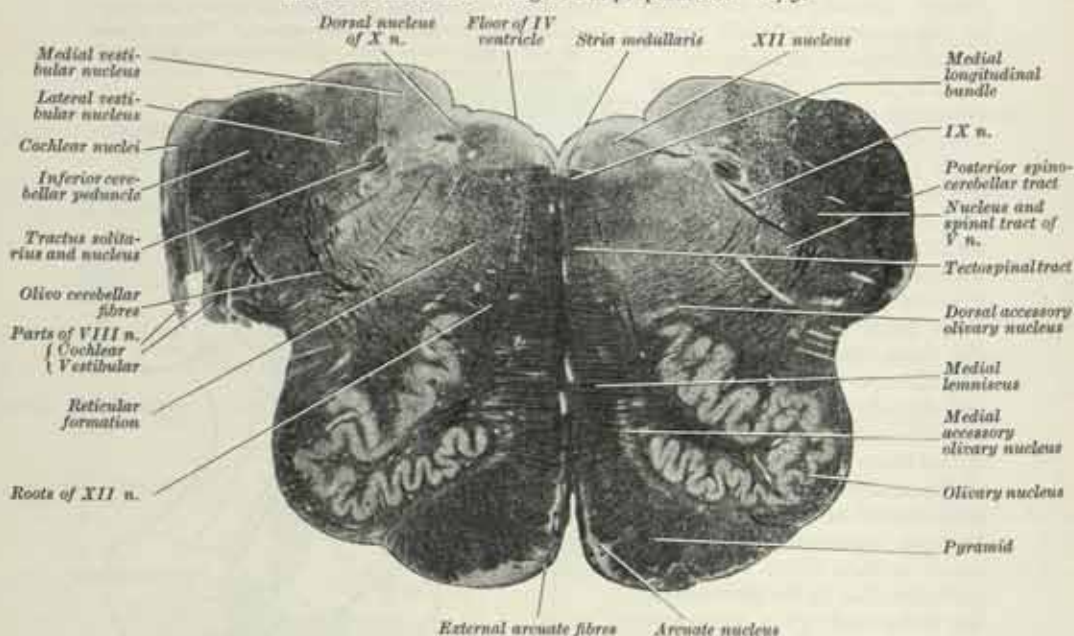
(3) *A transverse section through the medulla oblongata made on a level with the*

FIG. 830.—The nuclei of the cranial nerves schematically represented. Dorsal aspect. Motor nuclei in red; sensory in blue. (The olfactory and optic centres are not shown.)



lowest part of the fourth ventricle (fig. 831), shows the appearance of a number of new elements, together with most of those already described at a lower level. The total amount of grey matter shows a distinct increase owing to the presence of the large olivary nucleus, the nucleus arcuatus and nuclei associated with the glossopharyngeal, vagus and accessory nerves.

FIG. 831.—A transverse section through the medulla oblongata at the level of the middle of the olive. Weigert Pal preparation. $\times 4.5$.



The **olivary nucleus** is a large hollow mass of grey matter, with irregularly crenated walls and a longitudinal hilus, which is placed on its medial side. Situated dorsolateral to the pyramid, the nucleus underlies the surface elevation of the olive and extends upwards almost to the pons. The site of origin of its cells from the rhombic lip (p. 133) indicates a probable connexion with the vestibular apparatus and the cerebellum, and that such a connexion does exist is demonstrated by the large number of fibres which arise from the small cells of the nucleus and constitute the *olivocerebellar tract*. These fibres emerge from the hilus or through its medial wall, and run medially, intersecting the fibres of the medial lemniscus (figs. 831 and 834). They cross the median plane, and, sweeping dorsally, traverse the olivary nucleus of the opposite side, intersect the lateral spinothalamic and rubrospinal tracts and nucleus of the spinal tract of the trigeminal nerve and enter the inferior cerebellar peduncle, by which they are conveyed to the cerebellum. Despite the size of the nucleus and the ease with which its cerebellar connexions can be demonstrated, it has hitherto been found impossible to determine with certainty the afferent paths which lead to it. Several such pathways have, however, been described. It appears probable that fibres reach the nucleus from the spinal medulla, but whether they ascend in a separate spino-olivary tract or whether they are derived as collaterals from the fibres of the medial lemniscus and spinothalamic tracts, as Ramon y Cajal suggested, is not clear.* A group of fibres can be traced downwards through the mid-brain and pons, many of which are believed to end in the lateral aspect of the olivary nucleus, but, although they have been termed the thalamo-olivary fasciculus, their source of origin has not been demonstrated satisfactorily; some authorities ascribe them to the red nucleus, and others to the globus pallidus of the lentiform nucleus. This bundle of fibres is sometimes described as the *central tegmental fasciculus*,† and many of its constituents are continued downwards into the anterior intersegmental tract of the spinal medulla.

* A. Brodal, F. Walberg and Th. Blackstad, *J. Neurophysiol.*, **13**, 1950.

† S. A. K. Wilson, *Modern Problems in Neurology*, Wood & Co., New York, 1929; and F. A. Netter, *J. Comp. Neur.*, **80**, 1944.

The *medial accessory olivary nucleus* is a curved lamina of grey matter which is found at this level. The concavity of the curve is directed laterally and the nucleus is interposed between the medial lemniscus and the pyramid, on the one hand, and the medial and ventral aspects of the olivary nucleus on the other.

The *dorsal accessory olivary nucleus* is a second lamina of grey matter, placed dorsal to the medial part of the olivary nucleus.

Both the olivary and the accessory nuclei are intimately associated with the cerebellum. Phylogenetically, the accessory nuclei are older than the olivary nucleus, and they send their fibres to the palæocerebellum (p. 972). The olivary nucleus is found only in mammals and, in the course of evolution, it has enlarged in a tailward direction. The destination of its fibres in the human brain is in harmony with its phylogenetic history, for those which arise from its upper end and the lips of the upper part of the hilus pass to the palæocerebellum, whereas those from the larger, caudal portion proceed to the neocerebellum (p. 972). It has been demonstrated* that different parts of the olivary nucleus are each represented in a definite part of the cerebellar cortex, the relationship being of the 'point to point' type. The interdependence of the two has been emphasised by Brouwer, who has shown that neocerebellar atrophy is associated with a corresponding atrophy of all but the upper and medial part of the olivary nucleus.

On account of its intimate and free communication with the cerebellum it is clear that the olivary nucleus plays some intermediate part in muscular co-ordination and may therefore be regarded as a constituent part of the extrapyramidal system but no more definite statement can be made in the light of our present knowledge. Tilney suggests, on clinical grounds, that it is associated with the co-ordinative control of head and eye movements, while other clinical observations point to its association with palato-pharyngeal and laryngeal movements.

The *arcuate nuclei* form a curved, interrupted band of grey matter which is closely applied to the anterior and medial aspects of the pyramid; they appear to be caudally displaced nuclei pontis.† They give origin to the *anterior external arcuate fibres*, which emerge at the anterior median fissure and then course laterally and backwards over the surface of the medulla oblongata to enter the inferior cerebellar peduncle.

The central grey matter, which, at this level, is spread out over the floor of the ventricle, contains the *hypoglossal nucleus* and the *dorsal nucleus of the vagus*, and the *nucleus of the tractus solitarius* lies ventrolateral to the last-named; lateral to these, and on the medial side of the inferior cerebellar peduncle, the lower part of the *inferior nucleus of the vestibular nerve* may be recognised.

A small isolated group of large motor nerve-cells, termed the *nucleus ambiguus*, is placed deeply in the reticular formation. It extends upwards as far as the upper limit of the dorsal nucleus of the vagus. The fibres which emerge from its upper end join the glossopharyngeal nerve, and those which emerge at a lower level join the fila of the vagus nerve. Inferiorly it is continuous with a nucleus which gives origin to fibres of the cranial root of the accessory nerve (p. 1136). The fibres which arise from the cells of the nucleus ambiguus are all distributed to *striped muscle* of branchial origin (p. 132). These fibres first pass dorsally and medially for a short distance and then curve laterally to join the emerging fila of the vagus and glossopharyngeal nerves.

The nucleus gracilis and the nucleus cuneatus, now diminishing in size and irregular in outline, occupy the dorsilateral portion of the section, and ventral to them the *nucleus of the spinal tract of the trigeminal nerve* can be recognised without difficulty.

The white matter of the medulla oblongata shows little change at this level apart from the presence of the inferior cerebellar peduncle on the lateral side of the fourth ventricle. The pyramid, the medial lemniscus, the tectospinal tract and the medial longitudinal bundle occupy the same relative positions as they did at a lower level. The fibres of the olivocerebellar tract, sweeping across the median plane and turning dorsally to join the inferior cerebellar peduncle, have already been described in connexion with the olivary nucleus (p. 956). The *anterior external arcuate fibres* have their cells of origin in the arcuate nuclei and, emerging from the anterior median fissure, they run laterally, backwards and upwards over the pyramid, the olive and the

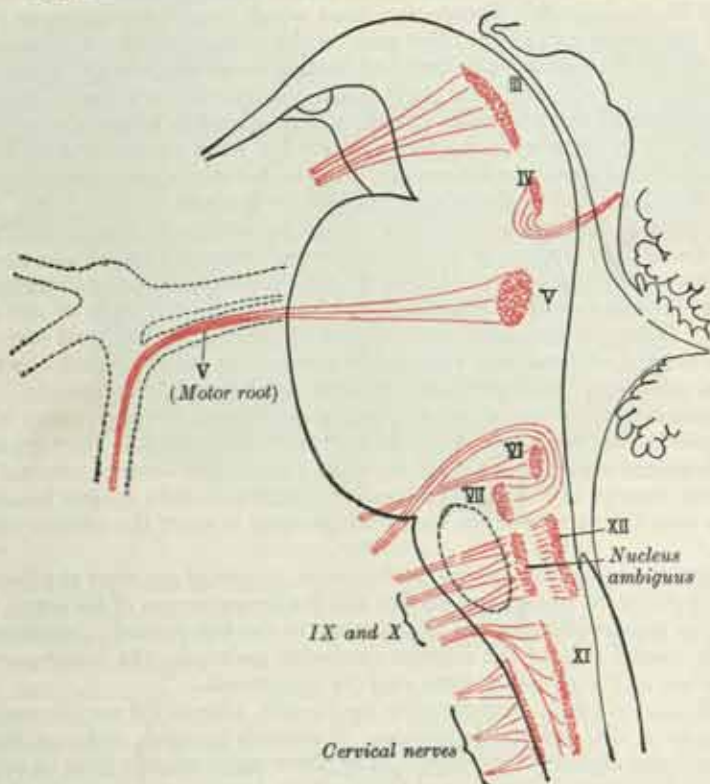
* G. Holmes and T. Grainger Stewart, *Brain*, 31, 1908; and A. Brodal, *Z. ges. Neurol. Psychiat.*, 169, 1940.

† A. T. Rasmussen and W. T. Peyton, *J. comp. Neurol.*, 84, 1946.

spinal tract of the trigeminal nerve. Coming into relationship with the posterior spinocerebellar tract, they ascend with it to enter the inferior cerebellar peduncle (fig. 835).

The *posterior external arcuate fibres* take origin in the *accessory cuneate nucleus*, which lies close to the dorsolateral aspect of the cuneate nucleus (fig. 829). This nucleus receives its afferents from the lateral fibres of the fasciculus cuneatus and sends its efferents directly into the inferior cerebellar peduncle. They provide the pathway to the cerebellum for proprioceptive impulses originating in the muscles of the upper limb and of the neck (p. 945).*

FIG. 832.—The nuclei of origin of the cranial motor nerves schematically represented on an outline of the brain-stem, viewed from the side.



The emerging fila of the hypoglossal nerve leave the ventral aspect of its nucleus and run forwards through the reticular formation. Passing lateral to the medial lemniscus and medial to the olivary nucleus, they curve laterally to emerge from the anterolateral sulcus. A relatively small lesion in the ventral part of the medulla oblongata at this level may therefore involve both the pyramidal tract and the hypoglossal nerve, causing a peculiar crossed paralysis. The muscles of the tongue are paralysed on the same side as the lesion, but it is the limbs of the opposite side of the body that are affected, for the lesion is situated above the level of the pyramidal decussation.

More dorsally, the reticular formation is traversed by the fibres of the vagus, travelling between the dorsal nucleus, the nucleus ambiguus and the nucleus of the tractus solitarius, with which they are connected, and the posterolateral sulcus where they emerge.

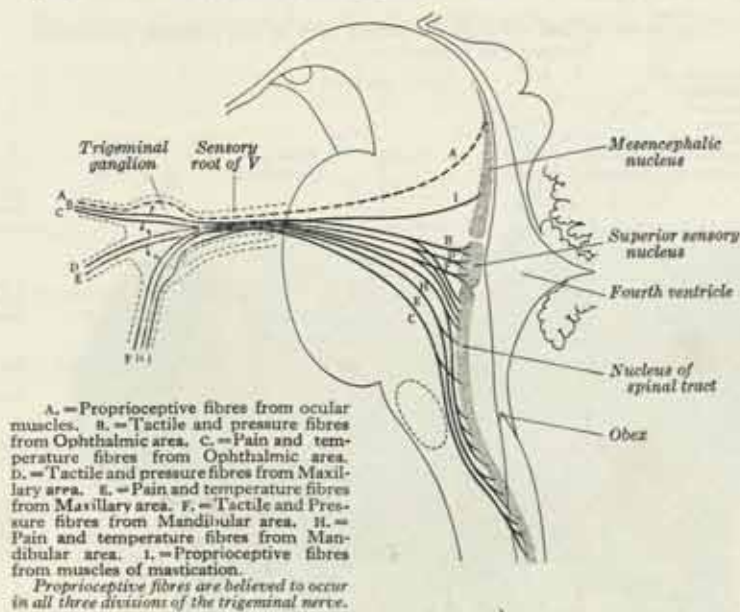
The *lateral spinothalamic tract*, which, at this and higher levels, is commonly termed the *spinal lemniscus*, (p. 944), lies dorsal to the olivary nucleus and separated from the surface of the medulla oblongata by the anterior spinocerebellar and the spinotectal tracts. It has been divided in this part of its course under local anaesthesia by an incision made close to the posterior border of the olive and in front of the rootlets of the vagus nerve. The incision is carried medially and backwards and, as it is

* A. Ferraro and S. E. Barrera, *Arch. Neurol. Psychiat.*, 33, 1935.

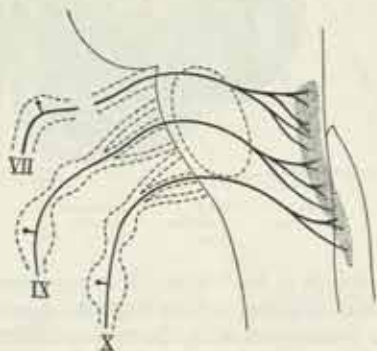
deepened, the foot, leg and thigh become analgesic, then the trunk is affected and, at a depth of 5 mm. analgesia spreads to the shoulder region,* demonstrating the

FIG. 833.—The primary terminal nuclei of the afferent fibres of some of the cranial nerves.

(A.) The afferent fibres of the trigeminal nerve.



(B.) The afferent fibres of the facial, glossopharyngeal and vagus nerves, conveying gustatory sensibility to the nucleus of the tractus solitarius.



Note.—The nucleus of the tractus solitarius is also regarded by many authorities as the primary terminal nucleus for fibres conveying general visceral sensibility through the vagus and glossopharyngeal nerves.

existence of a laminated arrangement in the tract similar to that described for the medial lemniscus (p. 955). As it ascends through the upper part of the medulla oblongata, the spinal lemniscus is closely related to the nucleus ambiguus, and a small lesion in the ventral part of the reticular formation may cause paralysis of the vocal fold and of the soft palate of the same side, but a loss of sensibility to pain and temperature on the opposite side of the body.

The reticular formation at the level of the lowest part of the fourth ventricle in the cat contains dorsally an extensive area concerned with expiratory movements and ventrally a similar area concerned with inspiratory movements.† Electrical stimulation of the latter abolishes rhythmic breathing and can fix the chest and diaphragm in maximal inspiration, leading to death unless the stimulation is discontinued. Clinical evidence ‡ points to a similar site for the respiratory centres in man.

(4) A transverse section through the uppermost part of the medulla oblongata shows

* H. S. Schwartz and J. L. O'Leary, *Archiv. Neurol. Psychiat.*, 47, 1942.

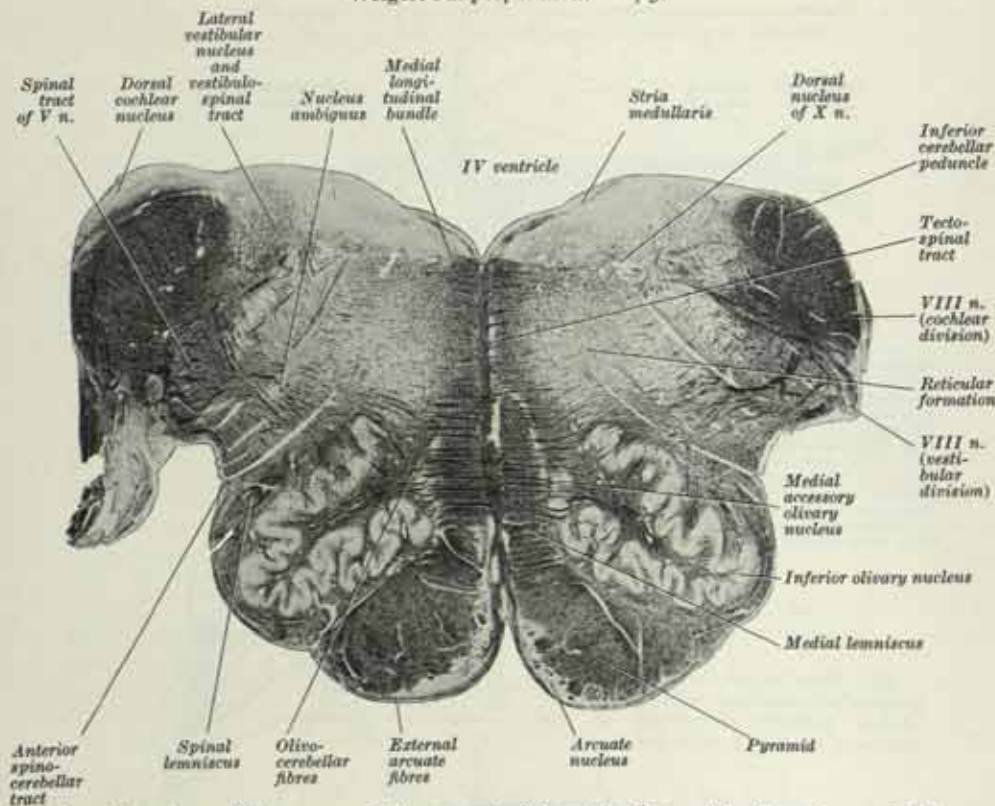
† R. F. Pitts, H. W. Magoun and S. W. Ranson, *Amer. J. Physiol.*, 126, 1939.

‡ K. H. Finley, *Arch. Neurol. Psychiat.*, 36, 1931.

less striking changes. The *olivary nucleus* occupies the same relative position, but the accessory olivary nuclei are being broken up and tend to disappear (Fig. 834).

Additional elements are present in the central grey matter. The *medial nucleus of the vestibular nerve* lies on the lateral side of the dorsal vagal nucleus, under the vestibular area of the rhomboid fossa. It is the largest of the four nuclear masses in which the fibres of the vestibular nerve terminate, and it extends upwards into the pons, where it spreads medially under the floor of the fourth ventricle and over the

FIG. 834.—Transverse section through the upper part of the medulla oblongata. Weigert Pal preparation. $\times 4.5$.



dorsal nucleus of the vagus. It is separated from the floor of the fourth ventricle by the *striae medullares* which cross it. Caudally the medial nucleus of the vestibular nerve is continuous with the *nucleus intercalatus* which is a small collection of cells in the lateral part of the trigonum hypoglossi and lying between the dorsal nucleus of the vagus and the upper end of the hypoglossal nucleus; its function is unknown. The cells of the medial vestibular nucleus give rise to axons which pass to the cerebellum and to the medial longitudinal bundle.

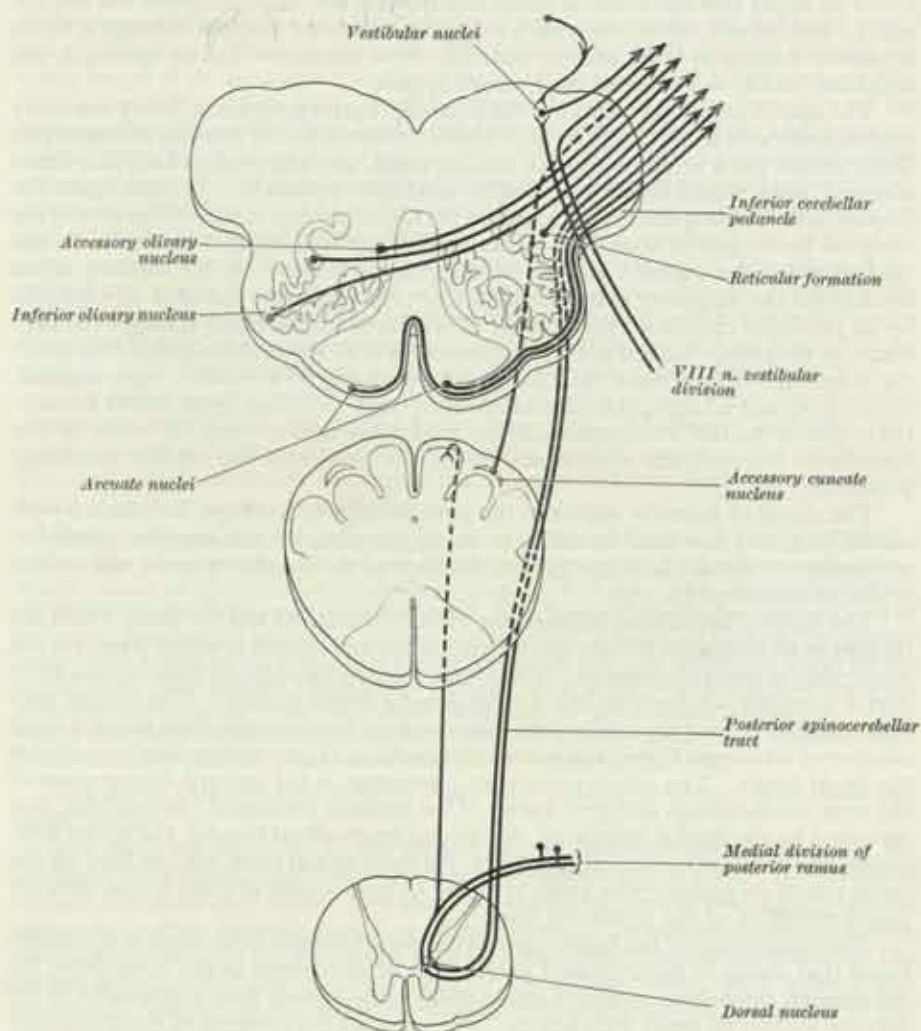
The *inferior nucleus of the vestibular nerve* lies on the lateral side of the medial nucleus, intervening between it and the inferior cerebellar peduncle. It extends to a lower level than the medial nucleus, but it does not extend so high into the pons. It receives the descending branches of the incoming fibres of the vestibular nerve and is said to contribute fibres to the vestibulospinal tract of the opposite side (p. 941).

The nucleus of the tractus solitarius, the nucleus of the spinal tract of the trigeminal nerve and the nucleus ambiguus show little alteration in position. Near the upper end of the nucleus ambiguus a small collection of cells in the reticular formation constitutes the *inferior salivary nucleus*. The fibres which arise in this nucleus join the fila of the glossopharyngeal nerve and ultimately reach the parotid gland (p. 1130).

The arrangement of the white substance at this level shows no conspicuous alteration. The spinal lemniscus ascends dorsal to the olivary nucleus, retaining the somato-topical arrangement already described (p. 959). The *inferior cerebellar peduncle* has increased in size and forms a well-marked elevation on the dorsolateral aspect of the medulla oblongata. Fibres from the olivary nucleus [olivocerebellar

tract], the arcuate nuclei of the medulla oblongata [anterior external arcuate fibres] and the posterior spinocerebellar tract of the same side have already been traced into it; in addition it receives the *posterior external arcuate fibres*, which join it from the accessory nucleus cuneatus of the same side (fig. 835), and parolivo-cerebellar fibres, derived from the accessory olivary nuclei. The constitution of the peduncle is completed by fibres which join it from the vestibular system and are destined for

FIG. 835.—A diagram to show the composition of the inferior cerebellar peduncle.



the cerebellum. These form a bundle, sometimes termed the *juxtarestiform body*, on the medial side of the inferior cerebellar peduncle.

The disposition of the *medial lemniscus* (p. 955) alters in the upper part of the medulla oblongata. Its ventral portion widens and becomes insinuated between the dorsal aspect of the pyramid and the narrowing upper end of the olivary nucleus. At the same time its dorsal portion recedes from the tectospinal tract and the medial longitudinal bundle, and so maintains continuity with the rest of the tract. This alteration in position is continued so that, as it enters the pons, the medial lemniscus comes to lie in a coronal plane (fig. 838) in the ventral part of the tegmental portion. The medial lemniscus comprises the second neurone fibres on the pathway of proprioceptive and tactile sensibility and in its course through the medulla oblongata it is joined by the fibres of the anterior spinothalamic tract (p. 941). On entry into the pons, therefore, the medial lemniscus contains all the proprioceptive,

tactile and pressure fibres from the lower limb, the trunk and the upper limb of the *opposite side* and there are good grounds for believing that the lower limb fibres are placed most laterally and adjoin those from the upper limb while those from the neck lie most medially.

THE PONS

The **pons**, or fore part of the hind-brain, is situated in front of the cerebellum. From its upper part the cerebral peduncles emerge, one on each side of the median plane. Behind and below, the pons is continuous with the medulla oblongata, but is separated from it in front and on each side by a transverse furrow in which the abducent, facial, and stato-acoustic nerves appear.

The *ventral or anterior surface* of the pons (fig. 824) is prominent, being markedly convex from side to side, less so from above downwards. It consists of transverse fibres arched like a bridge across the median plane, and gathered on each side into a compact mass which forms the middle cerebellar peduncle. It rests upon the dorsum sellæ of the sphenoid bone and on the upper portion of the basilar part of the occipital bone, and is limited above and below by well-defined borders. In the median plane the anterior surface of the pons is marked by the shallow *sulcus basilaris* for the lodgment of the basilar artery; this sulcus is bounded on each side by an eminence caused by the descent of the corticospinal fibres through the substance of the pons. Lateral to these eminences, a little above the middle of the pons, the trigeminal nerves make their exit, each consisting of a smaller, superomedial, motor root, and a larger, inferolateral, sensory root; vertical lines, drawn immediately lateral to the attachments of the trigeminal nerves, may be taken as the boundaries between the ventral surface of the pons and the middle cerebellar peduncles.

The *dorsal or posterior surface* of the pons, triangular in shape, is hidden by the cerebellum, and bounded laterally, in its upper part, by the superior cerebellar peduncles; it forms the upper part of the floor of the fourth ventricle, with which it will be described (p. 984).

The surface distinctions between the medulla oblongata and the pons, which are present in all mammals but are accentuated in the anthropoid apes and man, are not discernible in lower vertebrates. Transverse sections through the pons in man show that it is readily subdivisible into a ventral and a dorsal portion. The ventral portion, which is termed the *basilar part*, contains bundles of longitudinal fibres, a great number of transverse fibres, and scattered collections of grey matter which constitute the *nuclei pontis*. The dorsal portion, or *tegmentum*, is the upward continuation of the reticular formation and grey matter of the medulla oblongata. In addition, it is traversed by the medial lemniscus, the medial longitudinal bundle, the spinal lemniscus, the anterior spinocerebellar tract, the rubrospinal tract, etc., in fact, all the tracts which are passing from lower to higher or from higher to lower levels, with the single exception of the pyramidal tract.

The significance of the basilar part of the pons becomes clear when it is remembered that owing to the increased possibilities of movement in the mammalia, the mammalian cerebellum attains a vastly greater importance than it possesses in the nervous system of lower vertebrates. The complex movements of the mammalia demand perfect co-ordination for their proper execution, and it is assured by the connexions which develop between the cerebral cortex and the neocerebellum, through the medium of the nuclei pontis on the descending pathway, and through the medium of the thalamus on the ascending pathway. In man, large fibre tracts connect the cerebral cortex with the nuclei pontis, where they are relayed to the cerebellum.

The basilar part of the pons is an expression of the importance of the effector apparatus as an index of evolutionary progress. The intimate relationship between visual and auditory impressions on the one hand and the movements involved in speech and writing on the other demand a rich connexion between the visual, auditory and motor areas of the cortex with the cerebellum. In the complexity of his movements man is far ahead of his nearest relations in the animal kingdom, and in man, therefore, the basilar part of the pons attains its highest development.

In the lowliest mammals, such as *Echidna*, the basilar part is present only in the region of the pons which lies above the attachment of the trigeminal nerve. Its

enlargement in higher mammals is effected by its extension in a caudal direction. As a direct result of this extension, the sixth, seventh and eighth cranial nerves take their surface origin along its lower border.

Internal structure of the pons.—The *basilar part* presents a similar arrangement of its grey and white matter at all levels.

The *longitudinal bundles* comprise the corticopontine, corticonuclear and the important corticospinal (motor) fibres, which are continued downwards from the base of the cerebral peduncle. As they enter the upper limit of the basilar part of the pons, they form a compact collection of fibres, but they rapidly become broken up into numerous smaller bundles, separated from one another by the *nuclei pontis* and the transverse fibres of the pons. The *corticospinal fibres* descend through the whole length of the pons and enter the pyramid of the medulla oblongata, where they form a compact tract (p. 949). In their course through the pons they give off the *corticonuclear fibres* which run backwards, downwards and medially and cross the median plane to reach the motor nuclei of the fifth, sixth and seventh cranial nerves of the opposite side. Some authorities believe that the seventh cranial nerve also receives corticonuclear fibres from the same side. The *corticopontine fibres*, which are derived from the cerebral cortex, especially of the frontal, temporal and occipital regions, terminate at different levels in the nuclei pontis (fig. 836). The axons of the cells of the nuclei pontis form the *transverse fibres of the pons* and constitute the middle cerebellar peduncle. The frontopontine fibres terminate in the nuclei pontis above the level of the emerging roots of the trigeminal nerve and are relayed to the opposite half of the cerebellum as the upper transverse fibres of the pons.*

The *nuclei pontis* comprise all the masses of grey matter which are scattered everywhere throughout the basilar part of the pons. As already indicated, they constitute cell-stations on the pathway from the cerebral cortex to the cerebellum. The cells which constitute the nuclei pontis are derivatives from the rhombic lip which migrate ventrally and headwards.

All the cells which migrate in this direction do not succeed in reaching the basilar part of the pons. Some of them remain, forming an oblique ridge across the dorso-lateral aspect of the inferior cerebellar peduncle, and constitute the *nucleus of the circumolivary bundle* (corpus pontobulbare). The fibres to which this discrete part of the nuclei pontis gives origin run vertically upwards on the surface between the emerging seventh nerve on the medial side, and its sensory root and the eighth nerve on the lateral side. The afferent fibres to the nucleus traverse the whole length of the pons with the corticospinal fibres and leave them only in the medulla oblongata. They course obliquely backwards and upwards over the surface of the olive, to reach their destination, forming the *fasciculus circumolivaris pyramidis* (fig. 845).

The *dorsal part* of the pons shows many differences in structure, in its lower and upper parts.

The areas not occupied by the central grey matter, the named nuclei and the principal fibre tracts, constitute the *reticular formation* of the pons. It consists of scattered islets of grey matter, and forms a constituent part of the extrapyramidal system (p. 1076). Its main source of *afferent* fibres is the substantia nigra and the reticular formation of the mid-brain, by which it is brought under the control of the corpus striatum and the premotor cortex. Its *efferent* fibres, both crossed and uncrossed, descend to the spinal medulla in the reticulospinal tracts and to the reticular formation of the medulla oblongata (see also p. 954).

(A) The lower part of the tegmentum contains the motor nuclei of the sixth and seventh cranial nerves, the nuclei of the vestibular and cochlear divisions of the eighth nerve, and certain isolated collections of grey matter which will be described below.

The *medial nucleus* and the *inferior nucleus* of the vestibular nerve are continued upwards for a short distance into the tegmentum of the pons. The *lateral vestibular nucleus* is placed on the ventrolateral aspect of the medial nucleus, between it and the inferior cerebellar peduncle. This nucleus is characterised by the large size of its constituent cells, which is strongly suggestive of their motor character. Some of the fibres of the vestibular nerve are relayed in the lateral nucleus and the new fibres emerge from its medial side. They turn downwards and descend through the pons and medulla oblongata to enter the anterior funiculus of the spinal medulla, where they constitute the *vestibulospinal tract*. They end, uncrossed, by forming synapses

* See footnote *, page 973.

with the large motor cells of the anterior grey column, and they probably constitute the outgoing pathway for vestibulospinal reflexes.

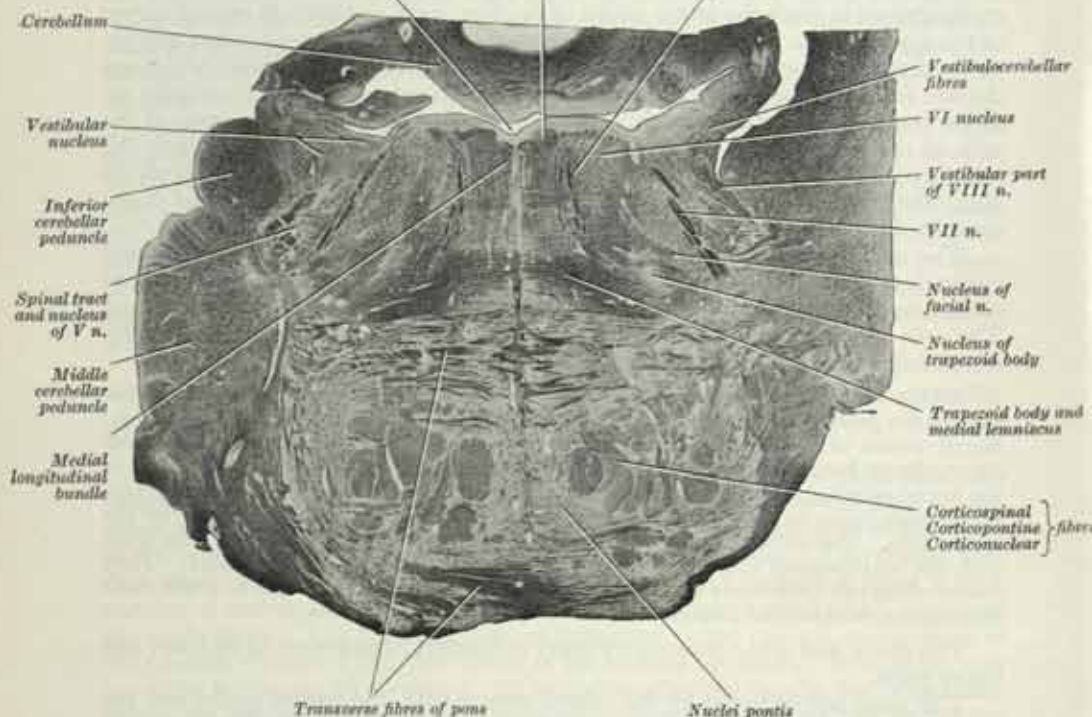
The *superior vestibular nucleus* extends to a higher level in the pons than the other nuclei of the vestibular nerve. It is continuous with the upper end of the lateral nucleus and occupies the superolateral portion of the vestibular area. The fibres of the vestibular system which are relayed in this nucleus may pass to the cerebellum or to the medial longitudinal bundle, of which they form an important constituent (see also p. 967).

The *ventral cochlear nucleus* is placed on the ventrolateral aspect of the inferior

FIG. 836.—Transverse section through the pons at the level of the facial colliculus.

Weigert Pal preparation. $\times 3.5$.

IV ventricle Geniculum of facial n. VI n.



cerebellar peduncle, as it passes upwards and laterally through the lower part of the pons. The nucleus receives afferent fibres from the cochlear nerve, and many of its outgoing fibres pass medially and rostrally through the substance of the tegmentum and decussate with corresponding fibres of the opposite side. In this situation they constitute the *corpus trapezoideum* and end in its posterior nucleus. Other outgoing fibres are relayed in the ipsilateral posterior nucleus of the corpus trapezoideum and ascend in the lateral lemniscus of the same side (fig. 838). Small islets of grey matter are found amongst the fibres of the corpus trapezoideum, from which they receive fibres and collaterals. These scattered collections of nerve-cells together form the *anterior nucleus of the corpus trapezoideum*.

The *dorsal cochlear nucleus*, which receives the descending branches of the fibres of the cochlear nerve, lies on the dorsal aspect of the inferior cerebellar peduncle and forms the auditory tubercle (p. 988). The fibres to which its cells give origin course medially, deep to the floor of the fourth ventricle to the median plane where they cross and decussate with the corresponding fibres of the opposite side. Continuing in a ventrolateral direction they join the fibres of the corpus trapezoideum, are relayed in its nuclei and help to form the *lateral lemniscus* (p. 992). Some of the fibres from the dorsal cochlear nucleus traverse the substance of the tegmentum to reach the nuclei of the corpus trapezoideum of the same side, where they are relayed to the ipsilateral auditory pathway (see also p. 1126).

The pathways followed by the second neurone fibres of the vestibular and cochlear nerves are not so sharply differentiated as might be supposed from the description given above. It would appear from the work of Winkler * and others that the vestibular nuclei (especially the lateral nucleus) contribute many fibres to the corpus trapezoideum and the lateral lemniscus, and that similar reflex movements may be induced both by vestibular and by cochlear stimulation (*see also* p. 995).

The *posterior (dorsal) nucleus of the corpus trapezoideum* is closely related to the corpus trapezoideum in the ventrolateral part of the reticular formation (fig. 836). It receives collaterals from many of the second neurone fibres of the ipsilateral eighth nerve and most, if not all, of the terminals of the contralateral second neurone fibres (fig. 950). Its efferents form the lateral lemniscus, which constitutes the auditory pathway and ascends to the lower auditory centres. In addition, a group of fibres emerges from its dorsomedial aspect and passes to the medial longitudinal bundle, forming the *peduncle* of the nucleus. These fibres probably reach the motor nuclei of other cranial nerves, particularly the nuclei of the trigeminal and facial nerves for reflexes involving the tensor tympani and stapedius muscles. It is possible that some fibres from the posterior nucleus pass directly to the nucleus of the sixth cranial nerve.†

The *striae medullares of the fourth ventricle* (auditory striae) are external arcuate fibres. They course across the floor of the fourth ventricle immediately deep to the ependyma. Laterally they extend to the lateral angle of the fourth ventricle; some enter the cerebellum and others pass to the *pontobulbar body* which is a collection of nerve cells lying just ventral to the ventral cochlear nucleus in the ventrolateral part of the brain stem at the junction of the pons and medulla oblongata. When traced medially the fibres of the striae medullares sink in at the median sulcus, decussate with the fibres of the opposite side and pass deeply to the arcuate nuclei which lie close to the midline ventral to the pyramid. The fibres of the striae medullares are not acoustic fibres as was formerly thought.†† Their precise connexion and function are not known.

The *nucleus of the abducent nerve* lies in the central grey matter a short distance from the median plane, and in line with the nuclei of the third and fourth cranial nerves, above, and the hypoglossal nerve, below. It is in close relation with the medial longitudinal bundle, which is placed to its ventrimedial side. In this way fibres from the vestibular and cochlear nuclei and the nuclei of other cranial nerves, especially the third nerve, have easy access to the sixth nucleus. It also bears an intimate relationship to the emerging fibres of the facial nerve (*see below*). The outgoing fibres of the sixth nerve pass ventrally and downwards through the reticular formation, intersecting the corpus trapezoideum and the medial lemniscus and traversing the basilar part of the pons to reach the surface at its lower border.

The *facial nucleus* lies in the ventrolateral part of the reticular formation of the pons, immediately behind the dorsal nucleus of the corpus trapezoideum. Dorsal to it, and somewhat to its lateral side, lies the *spinal tract of the trigeminal nerve* and its associated nucleus. The facial nucleus receives fibres from the pyramidal tract of the opposite side, a smaller number from the pyramidal tract of the same side, and also fibres from the rubro-reticular tract of the same side. Its large motor cells give origin to the fibres of the facial nerve. These fibres do not pass directly from their origin to the surface of the pons, but pursue a very remarkable course. At first they incline dorsally and medially towards the fossa rhomboidea, where they come into relationship with the abducent nucleus (fig. 837). They then course upwards on the medial side of this nucleus, coming into close relationship with the medial longitudinal bundle, by means of which the seventh nerve may be brought into communication with the other cranial nerves. Finally, the fibres of the facial nerve curve forwards and laterally over the upper end of the sixth nucleus forming the *geniculum of the facial nerve*. They then pass forwards, laterally and downwards through the reticular formation. In the last part of their course to the surface they pass between their own nucleus on the medial side and the nucleus of the spinal tract of the trigeminal nerve on the lateral side.

* C. Winkler, "The Central Course of the Nervus Octavus and its Influence on Motility," 1918. *Opera omnia*, vol. iv.

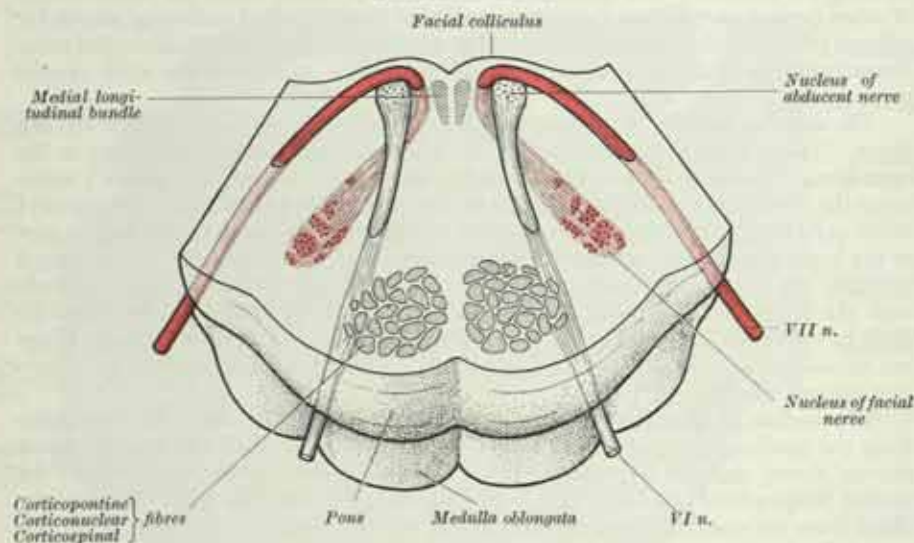
† A. T. Rasmussen and W. T. Peyton, *J. comp. Neurol.*, **84**, 1946.

†† T. H. Alphin and W. T. Barnes, *J. comp. Neurol.*, **80**, 1944.

The unusual behaviour of the emerging fibres of the seventh nerve provides striking evidence in favour of the theory of neurobiotaxis (p. 132). In the 10 mm. human embryo the facial nucleus lies in the floor of the fourth ventricle, occupying the position of the branchial (special visceral) efferent column, and at this stage it is placed at a higher level than the abducent nucleus. As growth proceeds, the facial nucleus migrates at first caudally, dorsal to the sixth nucleus, and then ventrally to reach its adult position. As it migrates the axons to which its cells give rise elongate, and their subsequent course maps out the pathway along which the facial nucleus has travelled.

It must be remembered that the facial nucleus not only receives fibres from the pyramidal tracts for volitional control, but it also receives fibres from its own sensory

FIG. 837.—Diagram to show the central course taken by the fibres of the facial nerve, viewed from above.



root (through the nucleus of the tractus solitarius) and from the nucleus of the spinal tract of the trigeminal nerve. These latter sources of stimulation complete local reflex arcs, in every way similar to the segmental reflex arcs in the spinal medulla. It is in an endeavour to retain its proximity to the nucleus of the tractus solitarius and to the nucleus of the spinal tract of the trigeminal nerve that the facial nucleus migrates from its original position in the basal lamina.

The nucleus of the facial nerve is subdivided into several parts. The cells which give rise to the axons innervating the muscles in the scalp and upper part of the face are placed towards the dorsal part of the nucleus and are believed to receive corticonuclear fibres from both sides.*

The *superior salivary nucleus* is closely associated with the inferior salivary nucleus and lies close to the rostral end of the dorsal nucleus of the vagus; it is dorsolateral to the caudal end of the motor nucleus of the facial nerve. It contributes to the facial nerve those fibres which are distributed, through the chorda tympani and the submandibular ganglion, to the submandibular and sublingual salivary glands.

The *nucleus of the spinal tract of the trigeminal nerve* is continued up through the lower part of the pons, the fibres of the tract still being closely applied to the lateral aspect of the nucleus. It is placed ventral to the lateral vestibular nucleus and is intersected by the fibres of the vestibular nerve which are destined for that nucleus. The inferior cerebellar peduncle lies to its lateral side below, but passes dorsally as it ascends to the cerebellum, and the spinal tract of the trigeminal nerve and its nucleus are subsequently related laterally to the middle cerebellar peduncle (see also p. 969). Above, the nucleus becomes continuous with the superior sensory nucleus of V.

In addition to tracts already studied at a lower level the white matter of the lower part of the tegmental region of the pons has the corpus trapezoidum,

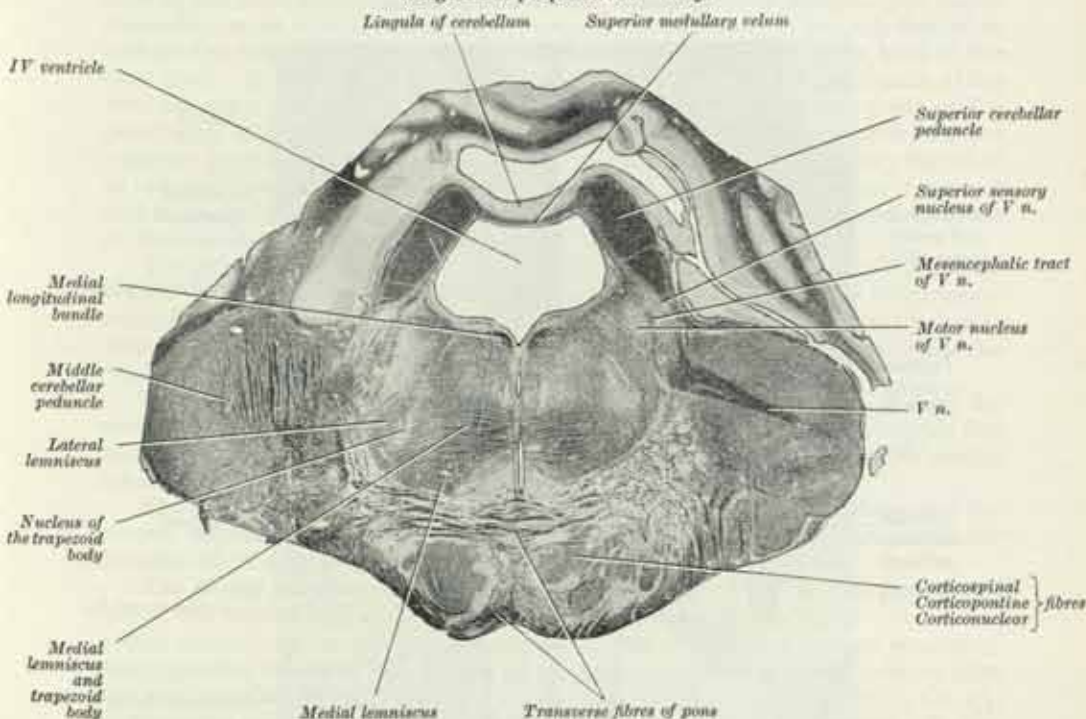
* J. W. Papez, *J. comp. Neurol.*, 42, 1927, and C. van Buskirk, *J. comp. Neurol.*, 82, 1945.

the lateral lemniscus and the emerging fibres of the sixth and seventh cranial nerves, which are new elements not present in the upper part of the medulla oblongata.

The *medial lemniscus* occupies the ventral part of the tegmentum. Its outline, on transverse section, is a flattened oval, extending laterally from the median raphe. The vertically running fibres of the medial lemniscus are intersected by the horizontal fibres of the corpus trapezoideum. Laterally they are related to the *spinal lemniscus* and to the *trigeminal lemniscus*. The fibres of the latter are derived from the cells of the nucleus of the spinal tract of the trigeminal nerve of the opposite side, and they convey painful and thermal impressions from the skin of the face, the mucous membranes of the conjunctiva, tongue, mouth, nose, etc.

The *corpus trapezoideum* is formed by fibres derived from the cochlear nuclei

FIG. 838.—Transverse section through the pons at the level of the trigeminal nerve.
Weigert Pal preparation. $\times 2.5$.



and from the nuclei of the corpus trapezoideum. They run horizontally and rostrally in the ventral part of the tegmentum, and, having intersected or passed ventral to the vertical fibres of the medial lemniscus, they cross the median raphe, decussating with the corresponding fibres of the opposite side. Before they reach the emerging fibres of the seventh nerve the fibres of the corpus trapezoideum turn upwards to form the *lateral lemniscus*, which is the ascending auditory pathway.

The course of the outgoing fibres from the nuclei of the sixth and seventh cranial nerves has already been examined.

The *medial longitudinal bundle* lies close to the median plane, immediately ventral to the floor of the fourth ventricle. It is closely related to the nucleus of the abducent nerve and to the emerging fibres of the facial nerve, as they ascend on the medial side of that nucleus. The proximity of the fasciculus suggests that it may receive fibres from and transmit fibres to both structures (p. 995). As it lies in the lower part of the pons, the medial longitudinal bundle receives fibres from the medial and superior vestibular nuclei and possibly from the posterior nucleus of the corpus trapezoideum (p. 965), through the peduncle of that nucleus. These contributions from the eighth nerve form the greater part of the fasciculus (p. 995).

(B) The tegmental region of the upper part of the pons contains new elements in connexion with the trigeminal nerve, but otherwise shows no very noticeable alteration.

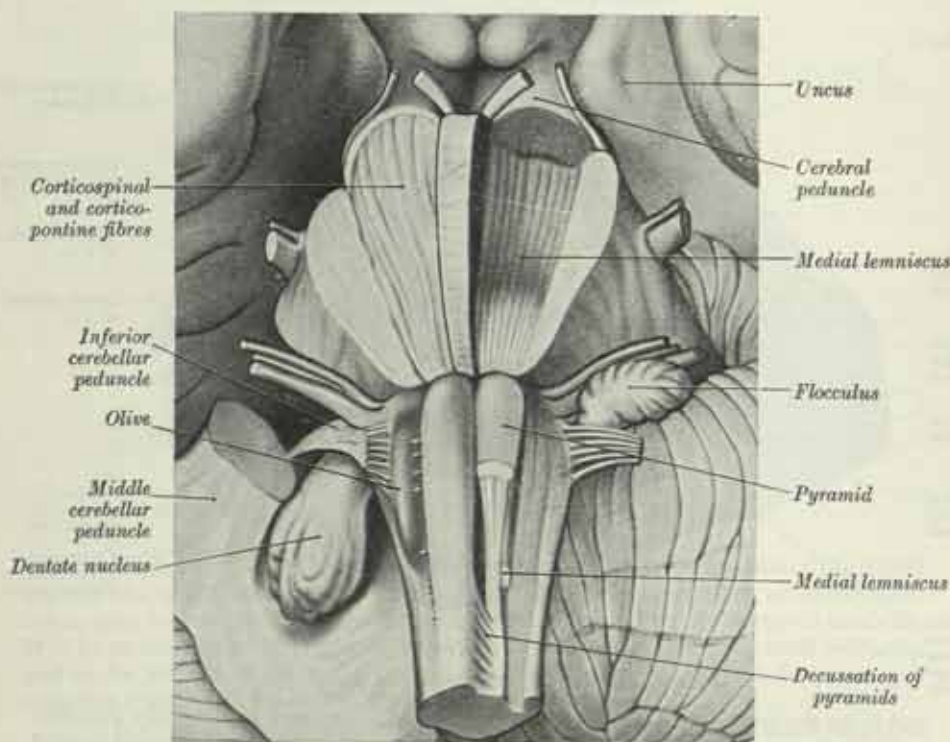
The *motor nucleus of the trigeminal nerve* is separated from the lateral part of the

floor of the fourth ventricle by a thin layer of central grey matter and by a part of the *formatio reticularis pontis*. The motor nucleus receives fibres from the corticonuclear tracts of both sides, especially the opposite side, and from the rubroreticular tract of the same side.

The *superior sensory nucleus of the trigeminal nerve* lies on the lateral side of its motor nucleus (fig. 838), intervening between it and the middle cerebellar peduncle, and is continuous below with the nucleus of the spinal tract.

The sensory root of the trigeminal nerve, unlike the sensory roots of the other cranial nerves, contains fibres of both cutaneous and deep sensibility. The superior sensory nucleus is, phylogenetically, a more recent acquisition than the nucleus of the spinal tract. It is absent in fishes: it is present, but of small size relatively, in

FIG. 839.—A dissection of the pons, the medulla oblongata and the right cerebellar hemisphere. Antero-inferior aspect.



Note.—In the pons and the medulla oblongata the dissection has been carried more deeply on the left (right side of figure) than on the right side.

Observe how the fibres of the medial lemniscus curve dorsally and then ventrally, as they ascend through the pons, and compare with fig. 865.

amphibia and reptiles, and it is constantly present in the mammalia. It therefore shows a close parallel to the nucleus gracilis and the nucleus cuneatus. On the other hand, the nucleus of the spinal tract, which is present in all vertebrates, is structurally identical with the substantia gelatinosa of the spinal medulla (p. 938) and is continuous with its upper end. On purely phylogenetic grounds, therefore, it would appear to be justifiable to associate the superior sensory nucleus with tactile and deep pressure sensibilities and the nucleus of the spinal tract predominantly with painful sensibility. However, histological and recent experimental and clinical evidence indicates that certain qualifications are necessary.

The incoming fibres of the sensory root comprise a smaller proportion of thick and a larger proportion of much finer fibres. Most of the thick fibres terminate in the superior sensory nucleus whereas the fibres descending in the spinal tract are predominantly fine fibres. It must, however, be stated that approximately 50% of the incoming fibres divide into ascending branches, which pass to the superior sensory nucleus, and descending branches, which enter the spinal tract. Such an

arrangement can only be explained if the two nuclei are, functionally, not so distinct from one another as their phylogenetic history would suggest.

By the use of the electrical method of investigation it has been shown that, when the skin and hairs of the face are stimulated by stroking with a camel-hair brush, action potentials are produced in the spinal tract of the trigeminal nerve.* The evidence so obtained demonstrates: (1) that the fibres of the ophthalmic nerve are placed ventrally in the tract and extend down to the lower limit of the first cervical segment of the spinal medulla: (2) that the fibres of the maxillary nerve lie in the central part of the tract and do not extend below the medulla oblongata: and (3) that the fibres of the mandibular nerve are placed in the dorsal part of the tract and do not extend much below the middle of the medulla oblongata. This experimental evidence is confirmed by the clinical results obtained after section of the spinal tract † in cases of severe trigeminal neuralgia. Section of the tract 4 mm. below the level of the obex renders the ophthalmic and maxillary areas analgesic but tactile sensibility, apart from the abolition of tickle, is not affected. When it is desired to include the mandibular area as well, the section must be made at the level of the obex itself. In addition, as a result of this operation, the mucous membrane of the tonsillar sinus, the posterior third of the tongue and the adjoining parts of the pharyngeal wall (glossopharyngeal nerve) and the cutaneous area supplied by the auricular branch of the vagus nerve are also rendered analgesic, and it may therefore be inferred that the fibres concerned join the spinal tract of the trigeminal nerve and end in its nucleus. During the course of these operations the laminated character of the tract has also been confirmed.

The second neurone fibres which arise in the nucleus of the spinal tract of V cross at once to the opposite side and ascend as the *trigeminal lemniscus*, which is intimately related to the spinal lemniscus in its passage through the upper part of the brainstem. The second neurone fibres from the superior sensory nucleus also cross the median plane and ascend in intimate relation with the medial lemniscus.

The *nucleus of the lateral lemniscus* is a small collection of cells placed on the medial aspect of the tract in the upper part of the pons. It receives collaterals and fibres from the lateral lemniscus, and some of its efferent fibres enter the medial longitudinal bundle.

The white matter of the tegmentum at this level is marked by the absence of the corpus trapezoideum, which is now replaced by the lateral lemniscus, and the invasion of its dorsolateral part by the superior cerebellar peduncles.

The *medial lemniscus* occupies a position in the ventral part of the tegmentum, but it has moved laterally a short distance from the median raphe. Here it is joined medially by the second neurone fibres from the superior sensory nucleus of the trigeminal nerve, which convey proprioceptive, tactile and pressure fibres from the area supplied by that nerve. More laterally it is related dorsally to the trigeminal and spinal lemnisci and to the lateral lemniscus and its nucleus. As the lateral lemniscus ascends, it passes dorsally and lies close to the surface. It will be seen subsequently to send its fibres into the inferior colliculus and the medial geniculate body. The *medial longitudinal bundle* retains its paramedian position.

The *superior cerebellar peduncle* is formed by a large collection of fibres which take origin in the dentate nucleus of the cerebellum (p. 982), and pass upwards and forwards to enter the lateral part of the roof of the fourth ventricle. As it ascends in this position it inclines forwards and medially and enters the dorsolateral part of the tegmentum. The *anterior spinocerebellar tract* is intimately associated with the foregoing. It has already been traced up through the medulla oblongata, where it lies dorsal to the olivary nucleus and separated from the surface only by the anterior external arcuate fibres. In the lower part of the pons it inclines dorsally between the sensory nucleus of the trigeminal nerve and the middle cerebellar peduncle until it reaches the lateral aspect of the superior peduncle. Its fibres then curve downwards and backwards to enter the cerebellum.

THE CEREBELLUM

The **cerebellum**, the largest part of the hind-brain, lies behind the pons and medulla oblongata, and its median portion is separated from these structures by the

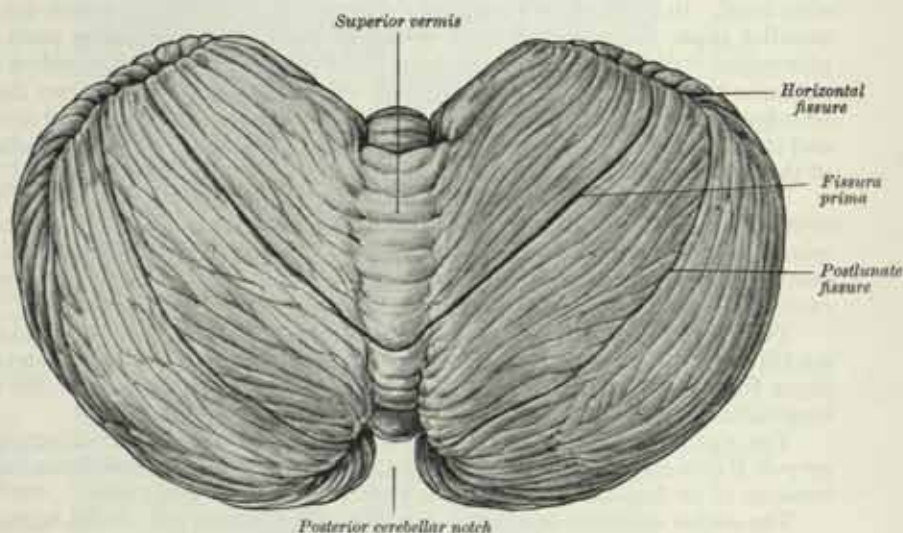
* F. Harrison and K. B. Corbin, *J. Neurophys.*, 5, 1942.

† G. E. Smyth, *Brain*, 62, 1939. A. Brodal, *Arch. Neurol. Psychiat.*, Chicago, 57, 1947, and Murray A. Falconer, *J. Neurol. Neurosurg. and Psych.*, 13, 1949.

cavity of the fourth ventricle. It lies in the posterior cranial fossa and is covered by the tentorium cerebelli (p. 1081). It is somewhat ovoid in form, but constricted in its median part, and flattened from above downwards, its greatest diameter being from side to side. Its average weight in the male is about 150 gms. In the adult the proportion between the cerebellum and cerebrum is about 1 to 8, in the infant about 1 to 20.

General form.—The cerebellum consists of two *cerebellar hemispheres* joined by a narrow median strip, the *vermis*. On the *superior surface*, however, there is no attempt at subdivision in the sagittal or parasagittal planes, so that the superior vermis, which is raised into a slight median ridge, is directly continuous with the hemisphere on each side. Anteriorly the superior vermis projects upwards beyond the free margin of the tentorium cerebelli, and from there it slopes downwards and backwards, related above to the straight sinus. The upper surface of each hemisphere is in contact with the tentorium cerebelli, and slopes downwards and laterally

FIG. 840.—The cerebellum. Superior aspect.



from the superior vermis. It is bounded, in front, by an anterolateral margin, which corresponds to the attachment of the tentorium cerebelli to the superior border of the petrous part of the temporal bone, and behind, by a curved posterior margin, which abuts against the transverse sinus as it lies in the attached margin of the tentorium cerebelli.

On the *inferior surface* the cerebellar hemispheres are separated from each other by a deep hollow, which is termed the *vallecula*. The inferior surface of the hemisphere is irregularly convex and lies in contact with the posterior surface of the petrous part of the temporal bone, the sigmoid sinus, the mastoid part of the temporal bone and the lower part of the squamous portion of the occipital bone. The *inferior vermis* projects into the floor of the vallecula and is limited on each side by the *sulcus valleculæ*.

Anteriorly the cerebellum presents a wide, shallow notch, which lodges the pons and the upper part of the medulla oblongata, but these portions of the brain-stem are separated from it by the fourth ventricle. In the floor of the anterior cerebellar notch the peduncles pass into the white centre of the cerebellum.

Posteriorly the hemispheres are separated from each other by the posterior cerebellar notch, which is a deep and narrow interval, lodging the falx cerebelli of the dura mater.

THE MORPHOLOGICAL SUBDIVISIONS OF THE CEREBELLUM

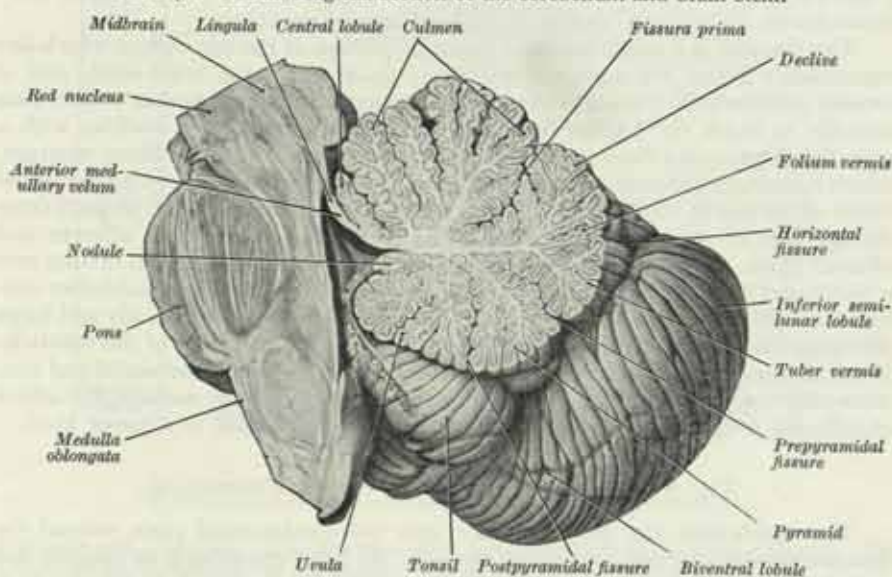
The surface of the cerebellum is everywhere marked by closely set transverse and somewhat curved fissures which give it a laminated appearance and separate its constituent *folia*. Some of the fissures are deeper than others and serve to sub-

divide the organ into lobules. The most conspicuous of these fissures is the *horizontal fissure*. This extends around the lateral and posterior borders of each cerebellar hemisphere from the middle cerebellar pedicle in front to the posterior cerebellar notch behind; it marks the junction of the superior and inferior surfaces of the cerebellum.

Superior surface (fig. 840).—The most conspicuous fissure on the superior surface is the *fissura prima*. This is somewhat V-shaped with its apex directed backwards and cutting into the superior vermis at the junction of its anterior two-thirds with the posterior third. The lines of the fissure are directed laterally and forwards around the superior surfaces of the cerebellar hemispheres and meet the horizontal fissures close to their anterior ends.

The superior vermis is subdivided by short, deep fissures into the *lingula*, *central lobule*, *culmen*, *declive* and *folium vermis* in that order from before backwards. Each of these subdivisions, except the lingula, is continuous laterally with the adjoining lobule of the cerebellar hemispheres (fig. 841). The fissura prima cuts the superior vermis between the culmen and declive.

FIG. 841.—Median sagittal section of the cerebellum and brain-stem.



The lingula consists of a single lamella which presents four or five poorly marked folia on its surface; its white matter is directly continuous with that of the anterior medullary velum. The lingula is separated from the central lobule by the *postlingual fissure*. The central lobule is continuous laterally with the *ala* of the central lobule. These are limited behind by the *postcentral fissure*. Between this fissure and the fissura prima lies the culmen medially and the *quadrangular lobule* laterally.

The superior surfaces of the cerebellar hemisphere and vermis behind the fissura prima is divided by the curved *postlunate fissure* into an anterior portion which consists of the declive with its lateral extensions, the *lobuli simplex* and the folium vermis with the adjoining parts of the cerebellar hemisphere termed the *superior semilunar lobules* which are limited behind by the horizontal fissures.

Inferior surface (fig. 843).—This surface includes the inferior vermis and the inferior aspect of each cerebellar hemisphere. The inferior vermis is subdivided into four smaller portions named from behind forwards the tuber vermis, pyramid, uvula and nodule. The tuber vermis is continuous laterally with the *inferior semilunar nodules*. These parts are bounded, behind, by the horizontal fissure and, in front, by the *prepyramidal fissure*. The pyramid is separated from the uvula by the *post-pyramidal fissure* or *fissura secunda* and is continuous laterally with the *biventral lobule* on the inferior surface of each hemisphere. In front of the uvula and separated from it by the median portion of the posterolateral sulcus is the nodule (figs. 841 and 843).

On the inferior aspect of the cerebellar hemisphere, in front of the biventral

lobule, is a deep fissure, the *retrotonsillar*, which passes laterally from the sulcus valliculæ opposite the fissura secunda and then curves forwards to gain the anterior part of the inferior surface of the hemisphere. Together with the anterior part of the sulcus valliculæ it bounds a circumscribed portion of the cerebellum, termed the *tonsil*, which is connected to the uvula across the floor of the sulcus valliculæ by a strip of cortex, termed the *furrowed band* (fig. 843). Superiorly the tonsil lies in intimate relation with the inferior surface of the inferior medullary velum.

The *nodule* is the most anterior part of the inferior vermis. Behind, it is separated from the uvula by the posterolateral fissure, and on each side it is connected to the flocculus and the white core of the hemisphere by the inferior medullary velum. Its antero-superior aspect is directed towards the fourth ventricle. Anteriorly it is covered with grey matter and crossed by two or three shallow fissures. In this situation it is separated from the ventricular cavity by a double layer of pia mater and its contained chorioid plexus, and the ventricular ependyma (fig. 852). Posteriorly the grey matter is deficient, and the white matter lies on the free surface, covered with a layer of neuroglia and the ependyma (fig. 852). The lateral aspect of the nodule is free anteriorly and is covered with grey matter; posteriorly, it presents a narrow strip, where its white core would be exposed, were it not directly continuous with the nervous layer of the inferior medullary velum.

The *flocculus* is a small, partially detached portion of the cerebellum which lies immediately below the stato-acoustic nerve as it enters the brain-stem, and is crossed anteriorly by the fila of the glossopharyngeal and vagus nerves as they pass laterally to reach the jugular foramen. It is somewhat oval in outline, with a crenated margin, and from its medial end a narrow band of white fibres emerges, which constitutes the *peduncle* of the flocculus; it is covered anteriorly by the lateral recess of the fourth ventricle and the part of the chorioid plexus which projects from the aperture of the recess (fig. 824). The peduncle contains both afferent and efferent fibres. At the lateral angle of the floor of the fourth ventricle it divides into a dorsal and a ventral part. Through the dorsal part the flocculus establishes connexions with the nodule and the uvula. The ventral part passes medially and turns upwards close to the lateral border of the pontine part of the floor of the ventricle. Many of these fibres are afferent and are derived from the vestibular nuclei and also, according to some authorities, from the medial accessory olivary nucleus, but others are efferent to the vestibular nuclei and some appear to ascend to a higher level.

THE FUNCTIONAL SUBDIVISIONS OF THE CEREBELLUM

The cerebellum can be subdivided into two fundamental parts termed the *flocculonodular lobe* and the *corpus cerebelli*, the latter comprising an anterior and middle lobe * † (figs. 842 and 844). These subdivisions possess functional as well as morphological and embryological significance. The *flocculonodular lobe* consists of both flocculi, their peduncles and the nodule. The *corpus cerebelli* comprises the remainder of the cerebellum and is separated from the flocculonodular lobe by the posterolateral fissure which is the first to appear on the cerebellum both in phylogeny and ontogeny. The *corpus cerebelli* is subdivided by the fissura prima into anterior and middle lobes. The *anterior lobe* lies in front of the fissure and comprises the lingula, central lobule, culmen, alæ of the central lobules and quadrangular lobules. The remainder of the *corpus cerebelli* is termed the *middle lobe* and comprises the declive, folium vermis, tuber vermis, pyramid, uvula, lobulus simplex, biventral lobules, semilunar lobules and tonsils.

Certain portions of the cerebellum are phylogenetically older than the rest. The flocculonodular lobe, which is exclusively vestibular in its connexions, together with the lingula, which receives spinocerebellar in addition to vestibular connexions, constitute the oldest part of the cerebellum, which is frequently termed the *archi-cerebellum*. The anterior lobe, excluding the lingula, but together with the pyramid and uvula, is phylogenetically the next part to appear and is predominantly spinocerebellar in its connexion, constituting the *paleocerebellum*. At this stage in phylo-

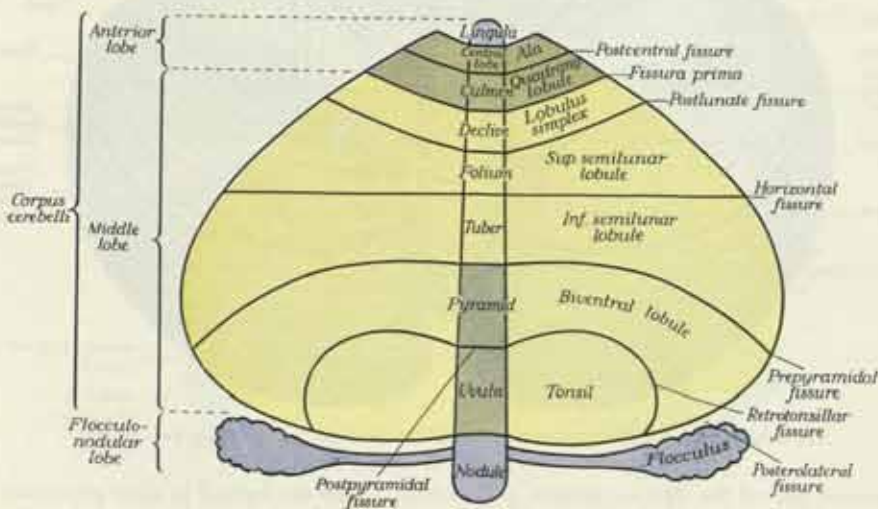
* The term posterior lobe used by some authorities is confusing as it may be used to designate either the middle lobe or the flocculonodular lobe or both these lobes together.

† For a review of recent work and full list of references to the literature see O. Larsell, *Arch. Neurol. Psychiat.*, 38, 1937; R. S. Dow, *Biol. Rev.*, 17, 1942, and J. Jansen and A. Brodal, *Aspects of Cerebellar Anatomy*, Oslo, 1954.

geny, this newly acquired lobe separates the archicerebellum into two parts, the lingula in front and the flocculonodular lobe behind. With the evolution of the neopallium in the mammal, there is a further expansion of the cerebellum with the addition of the middle lobe excepting the pyramid and uvula. This addition constitutes the *neocerebellum* and is predominantly corticocerebellar in its connexions.* Like the paleocerebellum, the neocerebellum intervenes between the anterior and flocculonodular lobes.

The **anterior medullary velum** is a thin lamina of white substance, which stretches between the superior cerebellar peduncles (brachia conjunctiva), and with them forms the roof of the upper part of the fourth ventricle; its deep surface is covered with the ventricular ependyma. The velum is narrow above, where it extends into the interval between the inferior colliculi, and broader below, where it is continuous with the white substance of the superior vermis. The folia of the lingula are prolonged on to the dorsal surface of its lower half, and a median ridge, termed the

FIG. 842.—Diagram to show the morphological and functional subdivisions of the cerebellum.



Blue=archicerebellum; Green=paleocerebellum; Yellow=neocerebellum.

frenulum veli, descends upon its upper part from between the inferior colliculi. The trochlear nerves emerge at the sides of the frenulum (fig. 851).

The **posterior medullary vela** form two thin, somewhat crescentic, sheets placed one on each side of the nodule. Each consists of a thin layer of white matter and neuroglia, covered on its upper aspect with the ventricular ependyma, and on its lower aspect with pia mater. Its superior surface forms the lower wall of the lateral dorsal recess of the fourth ventricle (p. 984); its inferior surface is related to the superior aspect of the tonsil. Its convex peripheral margin is continuous with the white core of the cerebellum and with the sides of the pyramid, uvula and nodule; its anterior (sometimes inferior) border is free (fig. 852) and from it the ventricular ependyma is prolonged downwards in close apposition with the pia mater to form the thin part of the roof of the ventricle and to reach the teniae. At its anterolateral corner the velum is continuous with the dorsal part of the peduncle of the flocculus, from which most, if not all, of its nerve-fibres are derived.

DEVELOPMENT OF THE CEREBELLUM †

Early in the third month the cerebellum is represented by a mass which stretches across the roof of the upper part of the hind-brain vesicle and presents the appearance of a dumb-bell (fig. 134). Its narrow median part is destined to form the vermis, and

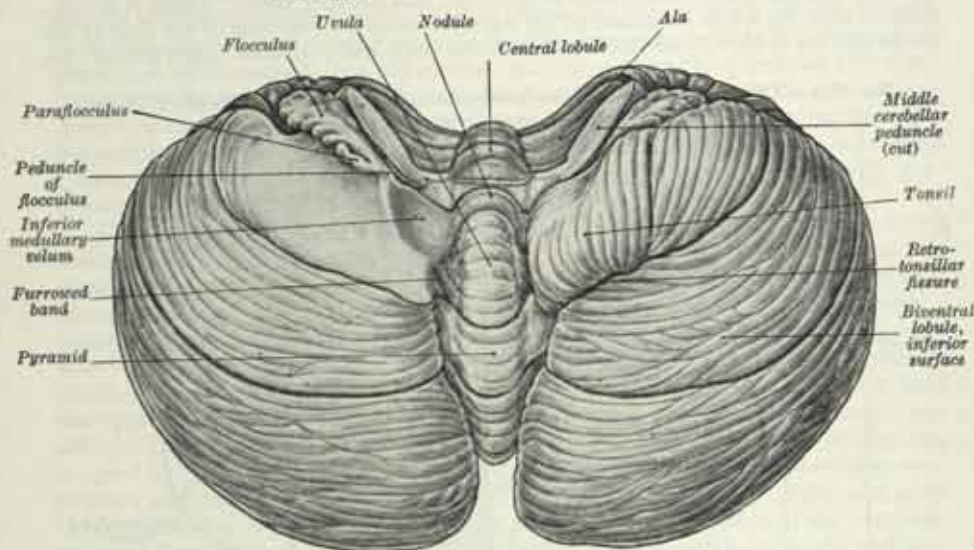
* According to Abbie the culmen receives, through the medium of the lower transverse fibres of the pons, numerous connexions from the temporal, parietal and occipital cortices, whereas the declive, folium vermis and tuber vermis receive similar connexions from the frontal cortex through the upper transverse fibres of the pons. For a detailed account, see *Proc. Roy. Soc. B.*, 115, 1934. *The Projection of the Forebrain on the Pons and Cerebellum*, By A. A. Abbie.

† O. Larsell, *J. comp. Neurol.*, 87, 1947.

its enlarged extremities develop into the hemispheres. As growth proceeds a number of transverse grooves appear on the dorsal aspect of the cerebellar rudiment, and give rise to the numerous fissures which characterise the surface of the cerebellum (figs. 843 and 844).

The lateral parts of the *posterolateral fissure* appear before any of the others and demarcate the most caudal portions from the rest of the cerebellar rudiment, enabling the flocculi to be identified. The right and left parts of this fissure extend medially and meet in the median plane, where they demarcate the nodule. The flocculonodular lobes can now be recognised and constitute the most caudal part of the cerebellum at this stage, but, owing to the growth of the adjoining areas, they come to occupy the

FIG. 843.—The cerebellum. Inferior aspect.



The tonsil and the adjoining part of the biventral lobule of the right side have been removed.

anterior part of the inferior surface in the adult. They are formed in close proximity to the line of attachment of the epithelial roof, i.e. to the rhombic lip (p. 133).

At the end of the third month a transverse furrow appears on the cephalic slope of the cerebellar rudiment, and deepens to form the *fissura prima*, which cuts into the vermis and both hemispheres, separating off the most headward portion of the rudiment to form the anterior lobe.

About the same period two short transverse grooves appear on the inferior vermis behind the postnodular fissure. The first of these is the *fissura secunda*, which demarcates the uvula, and the second is the *postpyramidal fissure*, which demarcates the pyramid (fig. 844). The whole cerebellum grows in a dorsal direction, and the caudal, or inferior, aspects of the hemispheres undergo much greater enlargement than the inferior vermis, which therefore becomes buried at the bottom of a deep hollow—the *vallecula*. While these changes are taking place numerous additional fissures develop, but they have little morphological significance. The most extensive of them forms the *horizontal fissure*.

In many mammals a portion of the hemisphere immediately cranial to the floccular fissure becomes demarcated and in some it forms a very prominent part of the cerebellum. Owing to its relation to the flocculus, it is termed the *parafocculus*, but the relationship is purely topographical, and, in contradistinction to the flocculus, the parafocculus derives its afferent connexions mainly, if not entirely, from the cerebral cortex. It is uncertain whether any homologue of the parafocculus exists in the human cerebellum, or whether it is represented by some small patches of grey matter which are found not infrequently on the inferior surface of the middle cerebellar peduncle.

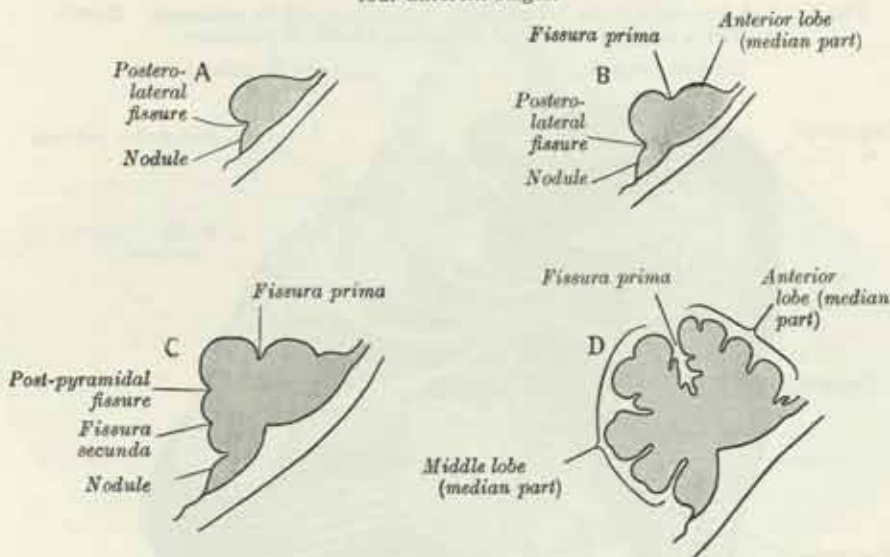
THE INTERNAL STRUCTURE OF THE CEREBELLUM

The cerebellum exhibits a profound difference in structure from the spinal medulla, the medulla oblongata and the pons, for the grey and white matter of which it is comprised are arranged in a precisely opposite manner. The grey matter is

found covering the whole surface of the cerebellum and dipping in to line the various fissures which cross its surface. It is true that certain aggregations of grey matter are found in its interior, but that does not in any way alter the importance of the peripheral distribution of the grey matter and the central arrangement of the white matter. In this way the cerebellum resembles the cerebrum, and it is this modification of the disposition of the grey matter which has rendered possible the enormous degree of expansion which these two parts of the nervous system have undergone during the process of evolution.

The **white matter** forms a central core, which is much thicker in the lateral parts than it is in the median area, where it forms a flattened strip connecting the enlarged lateral portions with each other. From its surfaces a series of nearly parallel plates or laminae project towards the surface, and these give off secondary laminae, usually more or less at right angles to the primary laminae. In turn the

FIG. 844.—Median sagittal sections through the developing cerebellum, showing four different stages.



secondary laminae may give off still shorter laminae, all of which are covered with grey matter. When a section is made through the cerebellum parallel with the median plane it divides the primary laminae at right angles, and the cut surface presents a characteristic branched appearance which is termed the *arbor vitae* (fig. 849).

The white matter of the cerebellum consists of (1) *fibræ propriae* and (2) *projection fibres*.

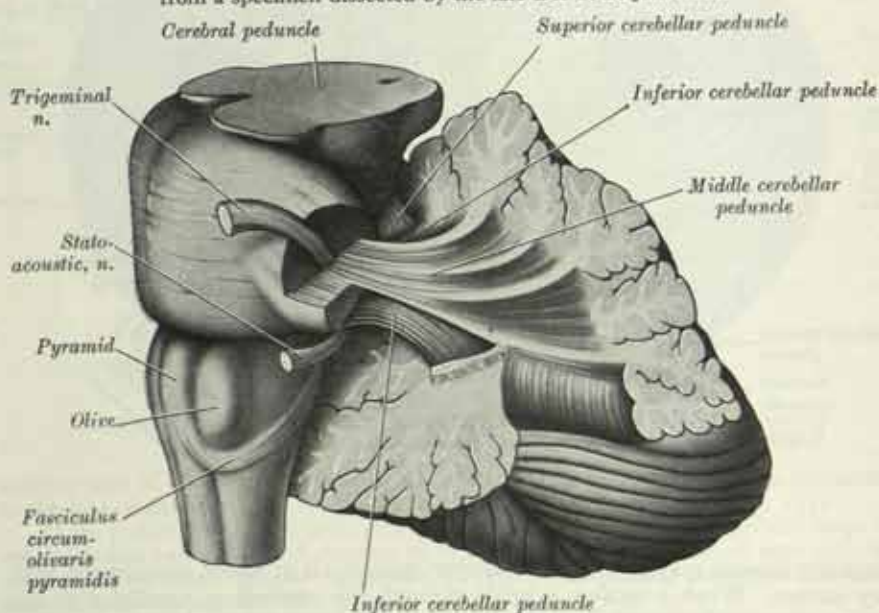
(1) The *fibræ propriae* do not leave the cerebellum, but connect different cortical areas with one another. They may cross the median plane, and in that event they are termed *commissural fibres*, or they may be ipsilateral—*association fibres*. Very little is known about the commissural fibres beyond the fact that they do not form any large bundles. The association fibres, too, for the most part run singly, and the available evidence suggests that they are relatively short and that they end as climbing fibres (p. 980).

(2) The **projection fibres** connect the cerebellum with other parts of the brain and the spinal medulla. They are grouped together into three large bundles or *peduncles* on each side and these issue from the anterior cerebellar notch. The superior peduncles connect the cerebellum to the mid-brain, the middle peduncles connect it to the pons, and the inferior peduncles connect it to the medulla oblongata.

The **superior cerebellar peduncles** emerge from the upper part of the anterior cerebellar notch and are hidden from view by the anterior lobe of the cerebellum. When that structure is pulled aside they can be seen connected with one another by the anterior medullary velum, and ascending in the lateral part of the roof of the fourth ventricle to disappear just below the inferior colliculus. The great majority

of the fibres which constitute this strand are efferent from the cerebellum and take origin, for the most part, in the cells of the nucleus dentatus. They emerge from the hilus of the nucleus and, having been joined by efferent fibres from the nuclei emboliformis and globosus, they pass upwards, forwards and medially, covered over at first by the medial fibres of the inferior and the deep fibres of the middle peduncle. As they ascend in the roof of the fourth ventricle the fibres gradually incline forwards, and sink into the tegmental region of the mid-brain under cover of the lateral lemniscus. They then sweep medially to decussate with the corresponding fibres of the opposite side. After the decussation the fibres divide into ascending and descending branches. Some of the ascending branches end in the red nucleus, but others are continued upwards into the rostral end of the ventral nucleus of the thalamus (p. 1003), whence they are relayed to the motor and premotor areas of the cortex (p. 1041). Others are said to proceed to the nuclei of the oculomotor and trochlear nerves. The descending branches can be traced downwards

FIG. 845.—A dissection of the left cerebellar hemisphere and its peduncles. Drawn from a specimen dissected by the late Dr. E. B. Jamieson.



through the pons into the medulla oblongata and, according to Cajal, they are continued into the anterior and lateral funiculi of the spinal medulla.

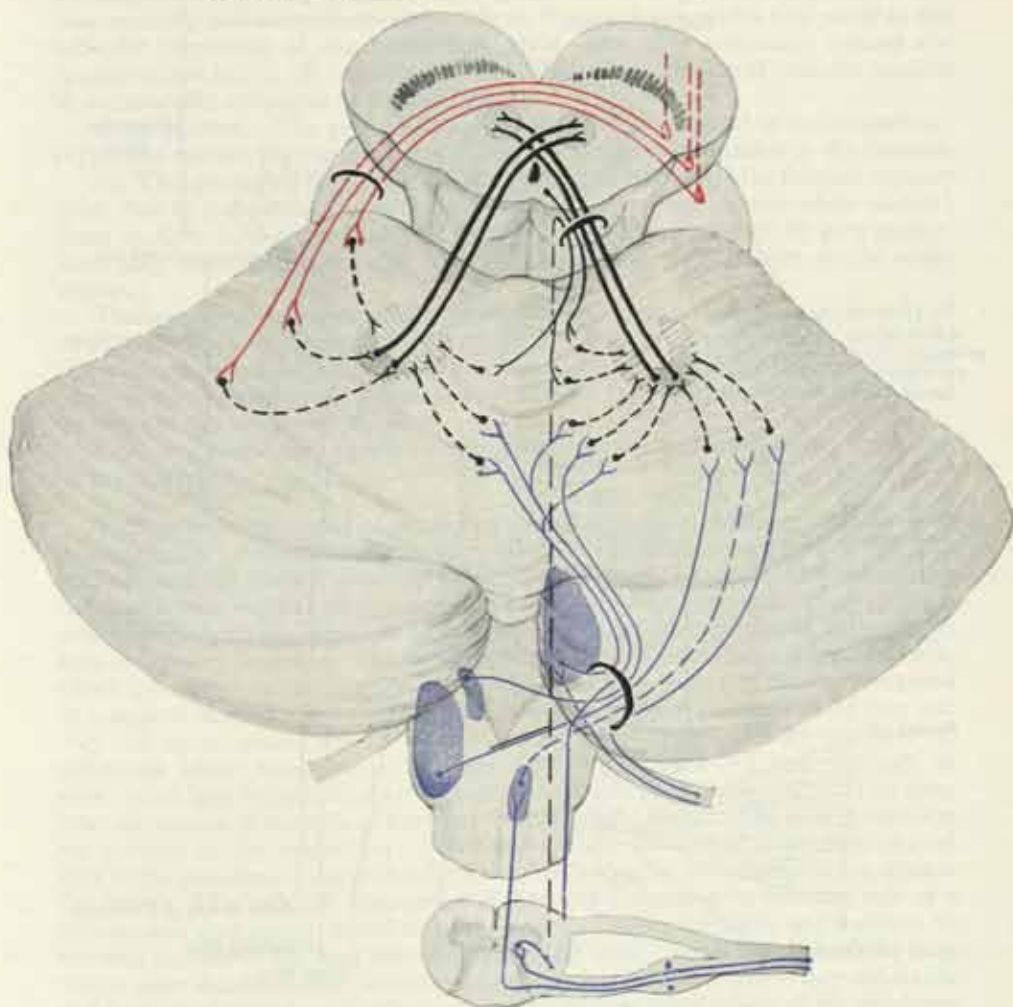
In addition to these efferent fibres the superior cerebellar peduncle contains the afferent fibres of the anterior spinocerebellar tract and a group of fibres which take origin in the tectum of the mid-brain and constitute a tectocerebellar pathway for the passage of visual impulses to the cerebellum. These two afferent tracts utilise the peduncle as a convenient mode of access to the cerebellum.

The fibres of the anterior spinocerebellar tract ascend from the spinal medulla (pp. 942 and 969), and terminate in the cortex of the superior vermis of the anterior lobe on both sides of the median plane. The projection of these fibres is not strictly limited to the vermis but extends to the lobes adjoining this part of the superior vermis. Nor is it strictly limited to the anterior lobe, for some fibres can be traced to the declive and the lobulus simplex of the middle lobe.

The **middle cerebellar peduncles** (fig. 845) are largely composed of fibres of the second neurone on the cortico-ponti-cerebellar pathway. They arise from the cells of the nuclei pontis of the opposite side and end in the cortex of the whole of the middle lobe of the cerebellum with the exception of the uvula. A few of the fibres encroach on the lateral part of the anterior lobe. In addition the middle cerebellar peduncles are said to contain some efferent fibres to the nuclei pontis, and others to the spinal medulla.

The fibres of each middle peduncle are arranged in three fasciculi, superior, inferior, and deep. The *superior* fasciculus is derived from the upper transverse fibres of the pons; it is directed backwards and laterally superficial to the other two fasciculi, and is distributed mainly to the lobules on the inferior surface of the cerebellar hemisphere, and to the parts of the superior surface adjoining the posterior and lateral margins. The *inferior* fasciculus is formed by the lowest transverse fibres of the pons;* it passes under cover of the superior fasciculus and is continued downwards and backwards more or less parallel with it, to be distributed to the folia on the under

FIG. 846.—The connexions of the cerebellum. Diagrammatic.



The constituent fibres of the inferior cerebellar peduncle = blue; those of the middle peduncle = red; those of the superior peduncle = black. The gracile, olivary, accessory olivary and vestibular nuclei are coloured blue; the dentate and red nuclei are shaded. The cerebello-thalamic fibres are not shown.

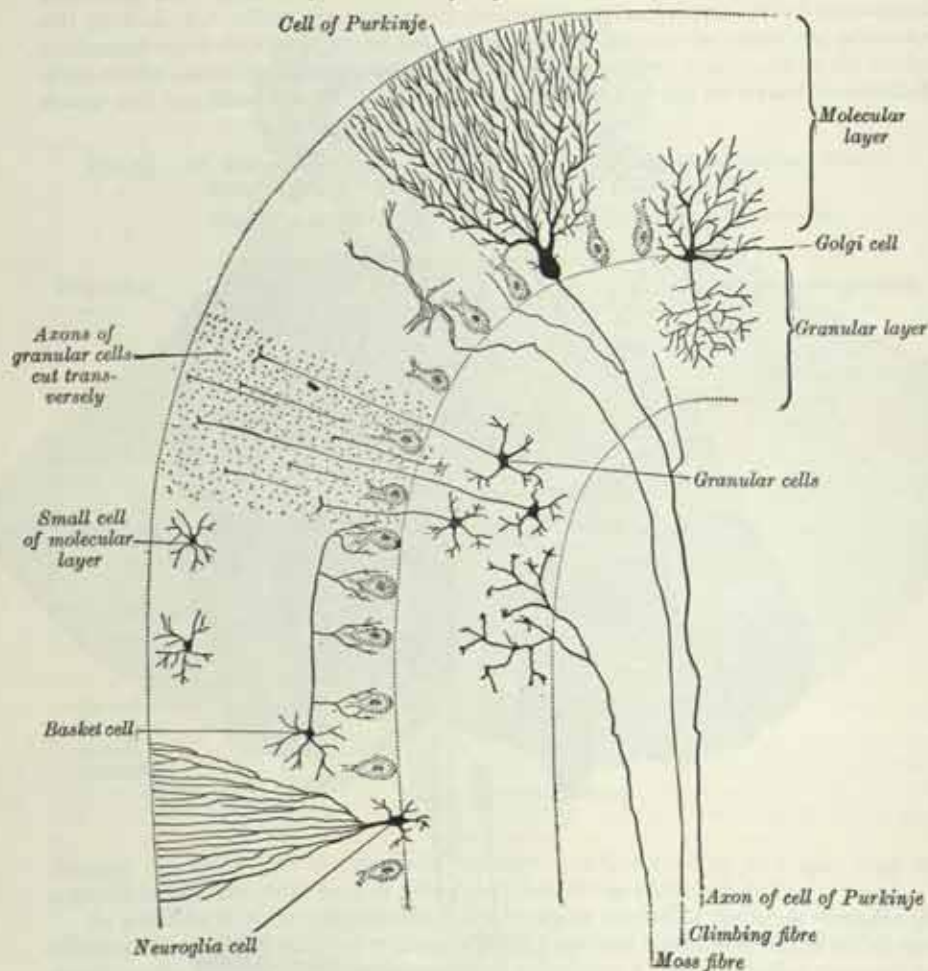
surface close to the vermis. The *deep* fasciculus comprises most of the deep transverse fibres of the pons. It is at first covered by the superior and inferior fasciculi, but crossing obliquely it appears on the medial side of the superior, from which it receives a bundle; its fibres spread out and pass to the upper anterior cerebellar folia. The fibres of this fasciculus cover those of the inferior peduncle.

The **inferior cerebellar peduncle** forms a second large tract of afferent fibres to the cerebellum. It draws its constituent fibres from a variety of sources, and they come together on the dorsolateral aspect of the upper part of the medulla oblongata.

* See footnote *, p. 973.

At the anterior cerebellar notch the tract bends backwards abruptly and insinuates itself between the superior and the middle peduncles. Each inferior peduncle contains the following fasciculi: (1) the posterior spinocerebellar tract, which ascends uncrossed from the spinal medulla. The majority of its fibres terminate in the vermis of the anterior lobe and the immediately adjacent parts of the adjoining lobules, extending further laterally than the fibres of the anterior spinocerebellar tract. Fibres from the posterior spinocerebellar tract also terminate in the pyramid,

FIG. 847.—A transverse section through a cerebellar folium. Diagrammatic. (After Ramón y Cajal and Kölliker.)



uvula and declive; * (2) the olivocerebellar tract from the olivary nucleus of the opposite side, which terminates for the most part in the cortex of the middle lobe and exhibit a point to point relationship between the olivary nucleus and the cerebellar cortex; (3) the parolivocerebellar fibres from the accessory olivary nuclei of the opposite side, which terminate in the cortex of the anterior and flocculonodular lobes, and of the vermis in the middle lobe; (4) the anterior external arcuate fibres from the arcuate nuclei of both sides (p. 957); (5) the posterior external arcuate fibres from the lateral cuneate nucleus of the same side. Both these groups

* R. S. Dow and R. Anderson (*J. Neurophys.*, 5, 1942), using the electrical method of investigation, confirmed the passage of proprioceptive stimuli from the muscles of the limbs to the pyramid. At the same time it is interesting to observe that they found that tactile stimuli applied to the hairs of the limbs aroused action potentials in the culmen and later in the pyramid and uvula (see also p. 983). J. Jansen and A. Brodal, *Aspects of Cerebellar Anatomy*, Oslo, 1954.

end in the cortex of the cerebellum, but their precise connexions have not been satisfactorily demonstrated (*see also* p. 958); (6) vestibular fibres, derived partly from the vestibular nuclei but largely from the vestibular division of the stato-acoustic nerve, occupy the medial part of the inferior peduncle in the juxtarestiform body. They terminate for the most part in the cortex of the flocculonodular lobe, and in the nucleus fastigii; some are believed to end in the lingula and a few in the uvula; (7) cerebello-vestibular fibres, which constitute an efferent pathway from the flocculus, nodule and nucleus fastigii to the vestibular nuclei. Most of the efferent fibres from the nucleus fastigii hook round the cerebellar end of the superior peduncle before joining the inferior peduncle. Soon they leave the peduncle and pass medially and ventrally to end partly in the vestibular nuclei and partly in the reticular formation of the brain-stem. The latter are sometimes termed the *fastigio-bulbar tract*; (8) reticulo-cerebellar fibres from the lateral reticular nucleus in the medulla oblongata to the cerebellum.

Grey matter.—The grey matter of the cerebellum is found in two situations:

(1) on the surface, forming the cortex; (2) as independent masses in the interior.

(1) The **grey matter of the cortex** presents a characteristic foliated appearance, due to the series of laminae which project from the central white matter; these in their turn give off secondary laminae, which are covered by grey matter. Externally the cortex is covered with pia mater; internally it rests on the white matter.

Throughout its whole extent the cerebellar cortex shows complete uniformity of structure. Local differences, which are so pronounced in the cerebral cortex, do not occur in the cerebellum, so that it is impossible to distinguish between sections taken from different areas. Not only is this the case in man, but it holds good throughout the vertebrate kingdom.

The cerebellar cortex consists of two layers, viz. an outer, molecular layer, and an inner, granular layer.

The *molecular layer* comprises superimposed superficial, intermediate and deep strata of nerve cells and a large number of non-medullated nerve-fibres. The cells of the superficial stratum consist of small pyramidal cells which send their dendrites and axons in a sagittal direction. The axons terminate by establishing synaptic relationships with the dendrites of the Purkinje cells which are found amongst the cells of the deep stratum. The intermediate stratum contains large pyramidal cells, which have been termed the '*basket*' cells. Their dendrites and axons also extend in a sagittal direction and the latter are clearly of great importance since they not only end by arborising around the body of a Purkinje cell, but they also give off collaterals which terminate in the same way. One basket cell may, through its axon, come into relationship with six or seven Purkinje cells (fig. 847). The deep stratum consists of the cells of Purkinje and the cells of Golgi. The cells of Purkinje are peculiar to the cerebellum; they form a single stratum of large, flask-shaped cells at the junction of the molecular and granular layers, their bases resting against the latter. The cells are flattened in a direction transverse to the long axis of a folium, and thus appear broad in sections carried across a folium, and fusiform in sections parallel to the long axis of a folium (fig. 848). From the neck of the flask one or more dendrites arise and pass into the molecular layer, where they subdivide and form an extremely rich arborescence, the various subdivisions of the dendrites being covered by lateral spine-like processes. This arborescence, like the cell, is flattened at right angles to the long axis of a folium; in other words, it resembles the branches of a fruit-tree trained against a trellis or a wall. Hence, in sections carried across a folium the arborescence is broad and expanded; whereas in sections parallel to the long axis of a folium, the arborescence, like the cell, is seen in profile, and is limited to a narrow area (fig. 848).

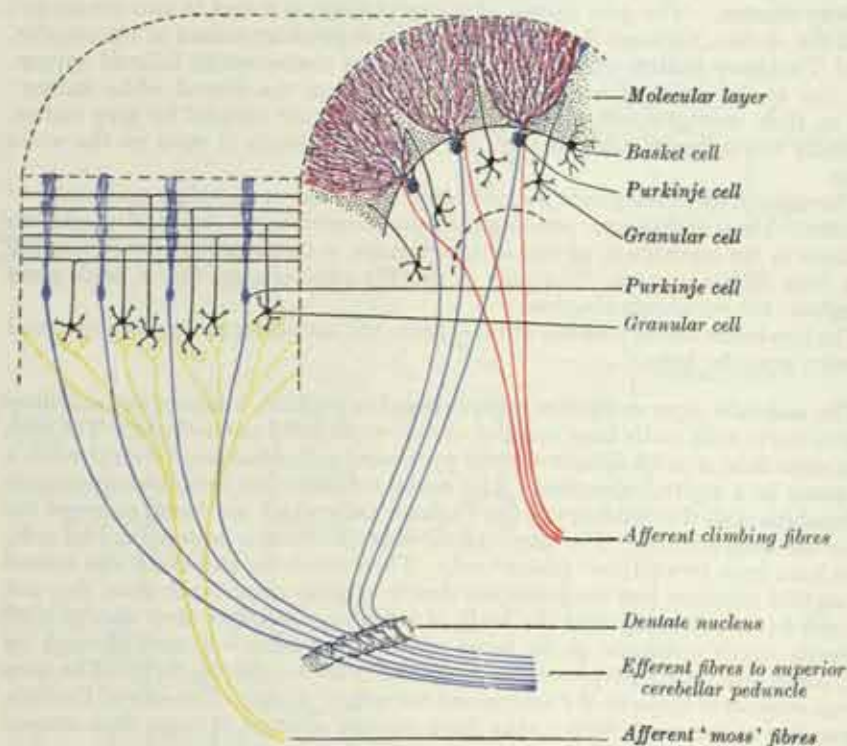
From the bottom of the flask-shaped cell the axon arises; this passes through the granular layer, and, becoming medullated, is continued as a nerve-fibre in the subjacent white matter. As it traverses the granular layer it gives off fine collaterals, some of which run into the molecular layer. *The axons of the cells of Purkinje terminate in the deep nuclei of the cerebellum.*

The *cells of Golgi* also lie at the junction of the molecular with the granular layer. Their axons are short (fig. 847) and end by forming synapses with the short dendrites of the granular cells. Their dendrites pass into the molecular layer

and form axodendritic synapses with the axons of the granular cells. These cells therefore provide a mechanism for the restimulation of the granular cells and so of the cells of Purkinje.

The nerve-fibres of the molecular layer are derived from several sources. (a) The axons of the cells in the granular layer pass into the molecular layer where they divide at right angles, the individual branches passing right and left in the long axis of the folium. As these branches traverse the folium they come into contact with dendrites of a large number of Purkinje cells, and they are described as forming *cruciate axodendritic synaptic connexions*. (b) Fibres enter the molecular layer from the white matter of the cerebellum. They come into intimate relation with the

FIG. 848.—Schematic representation of the intracortical connexions of the cerebellar projection fibres.



In the right part of the figure a cerebellar folium is shown in transverse section; in the left part of the figure, the same folium is shown cut parallel with its long axis.

Blue: cells of Purkinje and their axons. Red: 'climbing' fibres. Orange: 'moss' fibres.

dendrites of Purkinje's cells, breaking up into end filaments which follow the dendrites in their arborisations (fig. 848). They are termed 'climbing fibres', and their precise origin is still in doubt; although Cajal regarded them as the afferent fibres from the vestibular (in the palaeocerebellum) and pontine nuclei (in the neocerebellum), the view more generally accepted at the present time is that they represent association fibres. On the other hand their mode of termination in connexion with the dendrites of individual Purkinje cells is suggestive of a 'point to point' relationship* and the olivary complex has been shown to exhibit this relationship to the cerebellar cortex (p. 957). (c) The dendrites and the collaterals of the axons of the cells of Purkinje. (d) The dendrites and fibres of the nerve-cells which lie within the molecular layer. In addition to these there are other fibres which have a vertical direction and are the processes of large neuroglia cells situated in the granular layer. They pass outwards to the periphery of the grey matter, where they expand into little conical enlargements, which form a sort of limiting

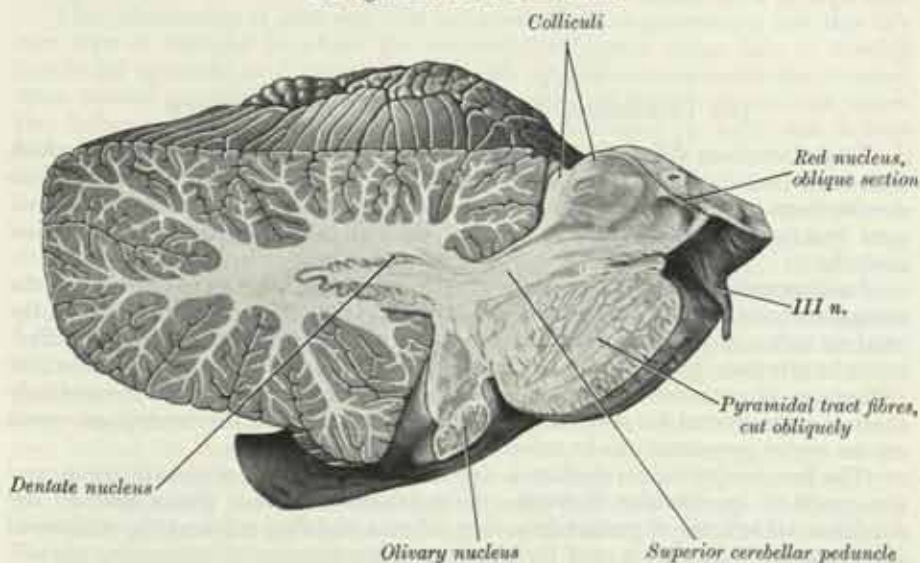
* R. S. Dow, *loc. cit.*

membrane beneath the pia mater, analogous to the *membrana limitans interna* of the retina.

The *granular layer* (fig. 847) contains numerous small nerve-cells together with many nerve-fibres. The *granular cells*, which are the most abundant of the elements of the cerebellar cortex, are small and round, with relatively large nuclei. Each cell is provided with four or five dendrites, which radiate out from it and end close to the cell body in fine terminal tufts. The axons of the granular cells have already been described in the molecular layer.

Many fibres enter the granular layer from the white substance of the cerebellum. Some merely pass through it on their way to the molecular layer (climbing fibres), but others end in the granular layer by dividing into numerous branches, on which peculiar moss-like appendages can be seen. They are termed *moss fibres*, and they end by forming synaptic connexions with the dendrites of the granular layer. Like the climbing fibres (p. 980), their precise origin is still in doubt. According to Cajal they are derived from the inferior cerebellar peduncle and especially from the spinocerebellar and olivocerebellar tracts. On the other hand there is considerable

FIG. 849.—A curved section through the right cerebellar hemisphere and the right half of the brain stem.



support for the belief that they represent the terminals of the principal afferent pathways to the cerebellum, namely, the vestibular, spinocerebellar and ponti-cerebellar fibres.*

Apart from the homogeneity of the cortex, the most striking feature of the minute anatomy of the cerebellum is the provision which is made for the multiple discharge of the impulses transmitted by the basket cells and the granular cells and the cells of Golgi into a large number of Purkinje cells. As each 'moss' fibre discharges into several granular cells, the number of Purkinje cells which can be stimulated by one 'moss' fibre is considerably magnified. It will be remembered that the Purkinje cells constitute the first neurones on the efferent pathway from the cerebellum, and this arrangement therefore provides a mechanism whereby an afferent impulse is able to bring about a widely distributed response.

(2) The **independent centres of grey matter** are embedded in the white matter of the cerebellum and are four in number on each side: one is of large size, and is known as the nucleus dentatus; the other three, much smaller, are situated near the middle of the cerebellum, and are known as the nucleus emboliformis, nucleus globosus, and nucleus fastigii. These nuclei receive the axons of the cells of Purkinje, and they therefore constitute cell-stations on the efferent pathways from the cerebellar cortex. It should be noted, however, that the flocculus and, probably, the nodule send efferent fibres direct to the vestibular nuclei.

* R. S. Snider, *J. Comp. Neur.*, 64, 1936.

The *nucleus dentatus* (fig. 849) is situated a little to the medial side of the centre of the white matter of the hemisphere. It consists of an irregularly folded grey lamina, containing a white centre and presenting, on its anteromedial aspect, an opening, termed the hilus, from which most of the fibres of the superior cerebellar peduncle emerge (p. 975). It is chiefly associated with the neocerebellum (p. 972).

The *nucleus emboliformis* lies close to the medial side of the nucleus dentatus, and partly covering its hilus. The *nucleus globosus*, an elongated mass, lies on the medial side of the nucleus emboliformis, and is directed anteroposteriorly. They are associated especially with those areas of the cerebellar cortex which receive afferent fibres from both the spinocerebellar and the cerebro-ponti-cerebellar pathways. In lower mammals these two nuclei form one mass termed the *nucleus interpositus*. The *nucleus fastigii*, somewhat larger than the other two, is situated close to the median plane in the anterior part of the superior vermis. It is phylogenetically the oldest of the cerebellar nuclei and is associated with the whole extent of the vermis. In addition to fibres from the cerebellar cortex it receives direct vestibular fibres and fibres from the vestibular nuclei. The axons of its cells give rise to the fastigiobulbar tract. All these nuclei lie in the upper wall of the lateral dorsal recess of the fourth ventricle (p. 984) and are separated from its cavity by a thin layer of white matter.

THE FUNCTIONAL SIGNIFICANCE OF THE CEREBELLUM

The cerebellum differs from the portions of the central nervous system which have been examined hitherto in showing no sign of segmentation at any stage of its development. It is entirely a suprasegmental structure, which presumably took over functions previously carried out in the individual segments of the spinal medulla.

Its outstanding feature, and one that differentiates it from all other parts of the central nervous system, is the homogeneity of the structure of its cortex. In the cerebral cortex it has been possible to map out a number of areas which show differences in structure (p. 1039), and it has been demonstrated in many instances that differences in structure are associated with differences in function. Accordingly there is good ground for supposing that the influence which the cerebellum exerts on the motor apparatus can be referred to one function only.

The function of the cerebellum is the ultimate refinement of co-ordination, and the result of its disorder is ataxia. Experimental evidence shows that all the fundamental reflexes of posture (standing reflexes, righting reflexes), the reciprocal innervation of antagonists, and the elementary combination of synergists, can still occur without the cerebellum. The fundamental disorder due to damage to the cerebellum or its connexions is irregularity in muscular contraction arising from the lack of appropriate integration of movement and posture. In addition, overshooting of the objective in limb movements, rhythmical tremor which develops as movement proceeds (action- or intention-tremor), irregular halting in any alternating movement (dysdiadochokinesis), interruption of the flow of syllables in speech (cerebellar dysarthria), tremor of the head and trunk (titubation), and deviation or staggering in gait are all signs of cerebellar lesions. In rapidly progressive disorder the affected limbs are more loosely held than normally (hypotonia), and lack of tone in the ocular muscles results in drifting of the eyes from the direction of the fixation point towards the position of rest with rhythmical correction of this failure of fixation (nystagmus). No appreciable change in any form of sensation is found.

The manner in which the cerebellum exerts appropriate control over the amplitude and timing of movement has yet to be ascertained. Hypotonia is not an essential part of cerebellar ataxia, and nystagmus, though commonly associated with expanding cerebellar lesions (abscess, tumour), is frequently absent in degenerative disease or after ablation.

Damage to the cortex of a cerebellar hemisphere induces ataxia in all movements of the limbs of the *same side of the body*. The disorder rapidly subsides owing to the great powers of compensation of the remaining cortex, but even in the acute stages it can be appreciably lessened by the concentrated effort of the patient. Conversely, the ataxia increases when the attention of the patient is diverted or his power of

concentration diminished, e.g. by alcohol. Only when both sides are damaged will ataxia become prominent in movements served by bilateral muscles. Thus lesions of the cerebellar vermis are associated with a greater degree of ataxia of station, gait and speech than of movement of individual limbs. Localisation of function in the cerebellar cortex is therefore not comparable to that in the cerebral cortex. Destruction of the dentate nucleus or superior peduncle has the same effect as damage to the corresponding hemisphere, but is of greater intensity and permanence, as might be expected from the absence of any alternative pathway.

Damage to the middle peduncle, or to the pons, also leads to cerebellar ataxia with preponderance of action tremor and nystagmus. The inferior peduncle is especially affected by thrombosis of the posterior inferior cerebellar artery, and a transient ataxia and hypotonia of the ipsilateral limbs results, together with involvement of the nuclei of the 5th, 9th and 10th cranial nerves and the spino-thalamic tracts (pp. 769 and 958).

It has been shown that the accessory olivary nuclei are associated with the vermis, while the larger part of the olivary nucleus is associated with the hemisphere, not in a general way but in a very particular manner, definite portions of the nucleus being associated with quite circumscribed areas of the cerebellar cortex of the opposite side (p. 957).

This relationship is seen not only in experimental degenerations but also in a rare type of disorder in which the neocerebellar system either fails to develop (cerebellar agenesis) or degenerates in middle age (olivo-ponti-cerebellar atrophy, often termed neocerebellar atrophy). Degeneration of the olivary nucleus occurs also following damage to the central tegmental fasciculus (p. 956), and is then associated with dysarthria and rhythmical tremor of the soft palate and larynx. It has been suggested therefore that the olivary nucleus may be particularly concerned with the cerebellar co-ordination of palato-pharyngeal and laryngeal mechanisms.

Functional localisation.—Studies in animals such as cat and monkey, have shown that the cerebellar cortex receives impulses from a wide range of receptors in all parts of the body. Tactile impulses from the skin, proprioceptive impulses from muscles and joints, impulses from the viscera as well as visual and acoustic impulses have all been shown to cause cortical activities which may be recorded as brief electrical changes from the surface of the exposed organ.* Impulses from the tail are received in the lingula, from the lower limb in the lobulus centralis and its alae, from the upper limb in the culmen and quadrangular lobule and from the face in an area behind the fissura prima. Optic and acoustic impulses are projected to the vermis caudal to the primary fissure. These areas have reciprocal connexions with the corresponding cerebral areas, with efferent pathways through the superior cerebellar peduncles and thalamus to the cortex and afferent pathways through the cortico-ponto-cerebellar system from the cerebral cortex. By these circuits close integration of cerebral and cerebellar activity can be maintained. If the circuit is broken or disturbed cerebral cortical control of voluntary movements results. The influence of the cerebellum on the cerebral sensory areas has not yet been elucidated.

Stimulation of the exposed cerebellar cortex in animals shows that the anterior parts of the cerebellum can influence limb movements. This may occur as a result of either facilitation or inhibition of a movement which has been evoked as a spinal reflex or by stimulation of the cerebral cortex.† Whether an increase or decrease of movement occurs depends upon the characteristic of the stimulus (i.e., its strength, duration and frequency). These actions can be related to pathways such as the cerebello-rubro-spinal or cerebello-reticulo-spinal through which the cerebellum can influence the motor neurones. Although the areas influencing movements agree roughly with the corresponding areas of afferent representation described above, present evidence is too contradictory to allow a precise localisation.‡ Ablations give only crude localisation of control because the production of detectable dysfunction requires the destruction of much cerebellar substance.

Clinical and experimental lesions relate cerebellar control to the movements of the homolateral limbs. In animals a bilateral afferent and efferent representation with considerable overlap of the parts represented is found in the paramedian or gracile lobules. The equivalent area in man is probably the posterior part of the

* E. D. Adrian, *Brain*, **66**, 1943. R. Snider, *Arch. Neurol. Psychiat.*, **64**, 1950.

† G. Morrucci, *Problems in Cerebellar Physiology*, Illinois, 1950.

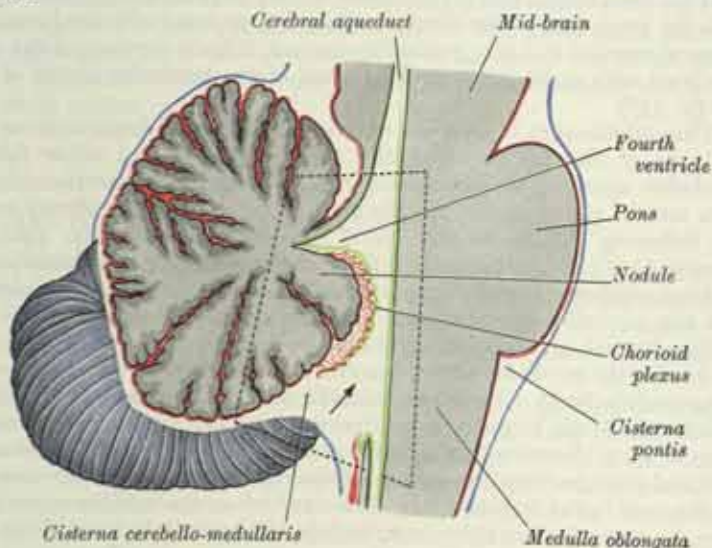
‡ J. Jansen and A. Brodal, *loc. cit.*

inferior semilunar lobule adjacent to the prepyramidal fissure but this has not yet been explored.

The exclusively vestibular connexions of the posterior lobe suggests that the flocculus and the nodule are mainly concerned with equilibration of the trunk and head; this has been confirmed to a large extent by experimental and clinical observations. The cells which form the cerebellum in the embryo migrate from the rhombic lip and especially from the region of the vestibular nuclei. This intimate relationship with the equilibratory centres does not necessarily mean more than that the adjustments evoked in equilibratory reflexes are fundamentally of the same type as those required in the co-ordination of other movements.

It should be emphasised that only the superior surface of the cerebellum is

FIG. 850.—Sagittal section through the brain-stem and the cerebellum close to the median plane. The black arrow is placed in the median aperture of the fourth ventricle.



The area enclosed by the interrupted lines is shown enlarged as fig. 852.
Blue: arachnoid mater. Red: pia mater. Green: ependyma.

readily accessible for experimental investigation and that much of the inferior surface which constitutes most of the middle lobe has yet to be investigated.

THE FOURTH VENTRICLE (figs. 850—853)

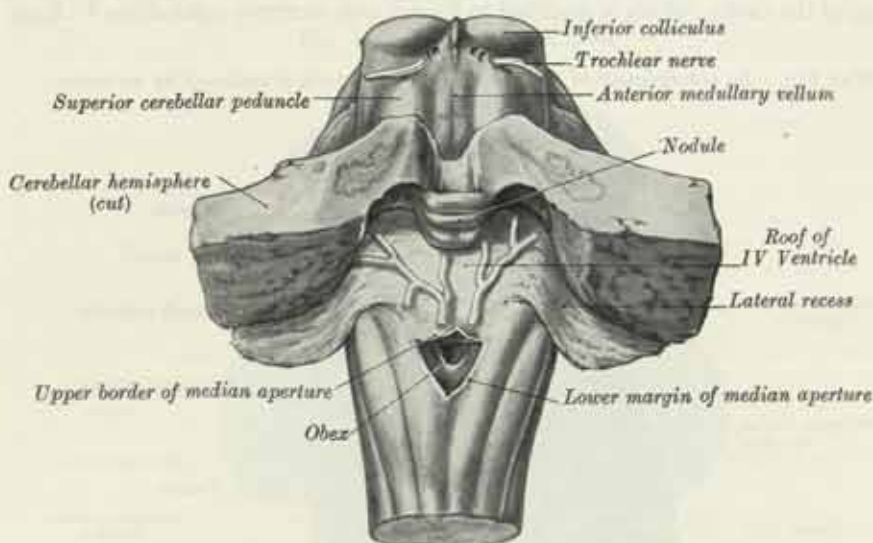
The **fourth ventricle** is a somewhat lozenge-shaped space situated in front of the cerebellum, and behind the pons and upper half of the medulla oblongata. Developmentally considered, it consists of three parts: a *superior* belonging to the isthmus rhombencephali, an *intermediate*, to the metencephalon, and an *inferior*, to the myelencephalon. It is lined with ciliated epithelium, and its inferior angle is continuous with the central canal of the medulla oblongata; its superior angle is continuous with the cerebral aqueduct, which opens above into the cavity of the third ventricle. From its middle part a narrow, curved pouch, named the *lateral recess*, is prolonged on each side between the inferior cerebellar peduncle and the peduncle of the flocculus, and reaches as far as the medial part of the flocculus itself. The recess is crossed anteriorly by the fila of the glossopharyngeal and vagus nerves and its lateral extremity is open, allowing a portion of the chorioid plexus of the fourth ventricle to protrude into the subarachnoid space (fig. 824). In the median plane the cavity extends dorsally into the white core of the cerebellum, forming a *median dorsal recess* (fig. 850) above the nodule, and on each side a *lateral dorsal recess* extends backwards still further (fig. 898), lying above the posterior medullary velum and below the cerebellar nuclei, from which it is separated by a thin layer of white matter.

The fourth ventricle possesses lateral boundaries, a roof or dorsal wall, and a floor or fossa rhomboidea.

Lateral boundaries.—The lower part of each lateral boundary is constituted by the gracile tubercle, the fasciculus cuneatus, and the inferior cerebellar peduncle; the upper part, by the superior cerebellar peduncle.

The roof or dorsal wall (fig. 851).—The upper portion of the roof is simple, and is formed by the superior cerebellar peduncles and the anterior medullary velum. The *superior cerebellar peduncles* (p. 975), on emerging from the central

FIG. 851.—The roof and the lateral recesses of the fourth ventricle, exposed from behind.



white matter of the cerebellum, pass upwards and forwards, forming at first the lateral boundaries of the upper part of the ventricle; on approaching the inferior colliculi, they converge, and their medial portions overlap the ventricle and form part of its roof. The *anterior medullary velum* (p. 973) fills the angular interval between the superior cerebellar peduncles, and is continuous behind with the central white matter of the cerebellum; it is covered on its dorsal surface by the lingula of the superior vermis (fig. 852).

The *lower part* of the roof is more complicated. Over most of its extent it consists of an exceedingly thin sheet, entirely devoid of nervous tissue and formed by the ventricular ependyma and the pia mater of the tela chorioidea of the fourth ventricle which covers it posteriorly (fig. 852). Below, the continuity of the sheet is broken by a gap, termed the *median aperture* (p. 986), through which the cavity of the ventricle communicates freely with the subarachnoid space. The *tela chorioidea of the fourth ventricle* is a double layer of pia mater which is carried upwards in the interval between the cerebellum and the brain-stem. Its posterior layer provides a covering of pia mater for the inferior vermis and, after reaching the nodule, is reflected forwards and downwards in immediate contact with the ependyma. Between the two layers of pia mater lie the vessels connected with the chorioid plexus of the fourth ventricle. On each side, the layers of the tela chorioidea reach the inferolateral borders of the ventricular floor, which is marked by a narrow, white ridge, termed the *tænia*, and the two *tæniæ* are continuous below with a small, curved fold, termed the *obex*, which covers the inferior angle of the ventricle and is lined with ependyma both in front and behind (fig. 852).

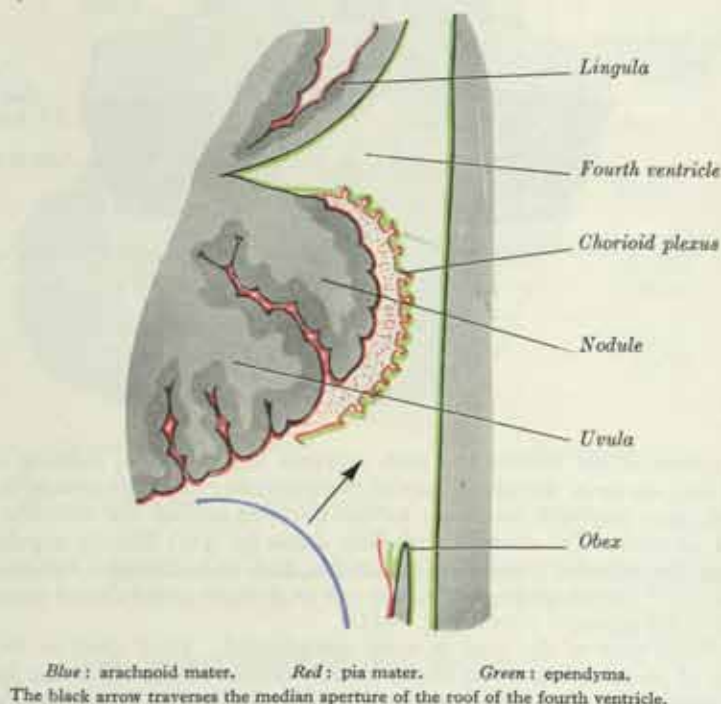
In addition, the ependyma-covered floors of the median and lateral dorsal recesses (p. 984) should, logically, be included as forming part of the morphological roof of the ventricle.

The openings in the roof.—In the roof of the fourth ventricle there are three openings, a median and two lateral. The *median aperture* is a large opening, situated

below the nodule (fig. 851); it varies considerably in its extent and its irregular upper border is drawn backwards towards the inferior vermis in a somewhat funnel-shaped manner (fig. 852). The *lateral apertures* are placed at the ends of the lateral recesses and they are partly occupied by portions of the chorioid plexus, which protrude into the subarachnoid space (fig. 824). Through these openings the ventricular cavity communicates with the subarachnoid space, and the cerebrospinal fluid can circulate from the one cavity to the other. Occasionally one of the lateral recesses may fail to open into the subarachnoid space, but the median aperture is constantly present.

The chorioid plexuses.—Two highly vascular fringe-like processes of the tela chorioidea contain the chorioid plexuses of the fourth ventricle; they invaginate the lower part of the roof of the ventricle and are everywhere covered by the epithelial lining of the cavity, which is modified to form a true secretory epithelium.* Each

FIG. 852.—An enlargement of the part of fig. 850, which is enclosed by an interrupted black line.



consists of a vertical and a horizontal portion: the former lies close to the median plane, and the latter projects into the fourth ventricle, passes into the lateral recess and emerges through the lateral aperture still covered by ependyma. The vertical parts of the plexuses are distinct from each other, but the horizontal portions are joined in the median plane; and hence the entire structure presents the form of the letter T, the vertical limb of which, however, is double. Numerous small tufts of the plexus are associated with the drawn-back upper wall of the median aperture and project into the subarachnoid space (fig. 852), like the tufts which protrude from the foramina of the lateral recesses.

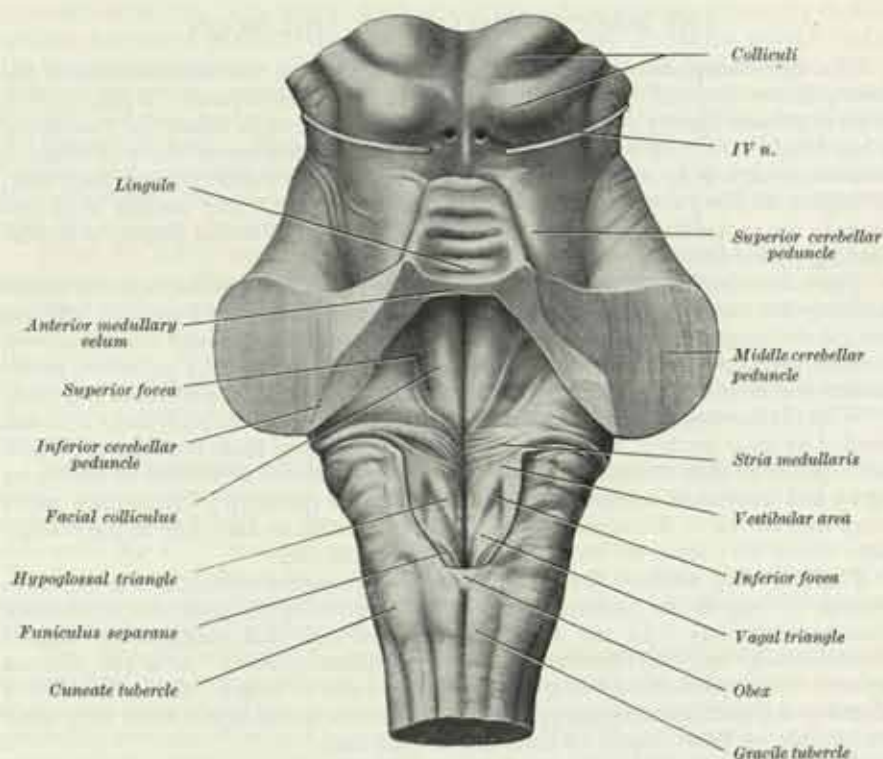
The fossa rhomboidea (floor of the fourth ventricle) (fig. 853).—The anterior wall or floor of the fourth ventricle is rhomboidal in shape; it is formed by the posterior surfaces of the pons and open part of the medulla oblongata. It is covered by a layer of grey matter continuous with that surrounding the central canal of the medulla oblongata and spinal medulla; superficial to this there is a thin lamina of neuroglia covered with a layer of ciliated epithelium, which consti-

* W. E. Le Gros Clark, *Tissues of the Body*, Clarendon Press, Oxford, 1951.

tutes the *ependyma* of the ventricle. The floor consists of three parts, superior, intermediate and inferior. The *superior* part is triangular in shape and limited laterally by the superior cerebellar peduncles; its apex, directed upwards, is continuous with the cerebral aqueduct; its base is represented by an imaginary line at the level of the upper ends of two small depressions, named the superior foveæ. The *intermediate* part extends from this level to that of the horizontal portions of the tæniæ of the ventricle and is prolonged into the lateral recesses. The *inferior* part is triangular, and its downwardly directed apex is continuous with the wall of the central canal of the closed part of the medulla oblongata.

The fossa rhomboidea is divided into symmetrical halves by a *median sulcus*, which reaches from its upper to its lower angle and is deeper below than above. On each side of this sulcus there is an elevation, termed the *medial eminence*, bounded

FIG. 853.—The rhomboid fossa.



laterally by a sulcus which represents the *sulcus limitans*. In the superior part of the floor the medial eminence has a width equal to that of the corresponding half of the floor, but opposite the superior fovea it forms an elongated swelling, named the *facial colliculus*, which overlies the nucleus of the abducent nerve, and is in part produced by the ascending portion of the root of the facial nerve. In the inferior part of the floor the medial eminence assumes the form of a triangular area, termed the *hypoglossal triangle* or *trigonum hypoglossi*. When examined under water with a lens the hypoglossal triangle is seen to consist of a medial and a lateral area separated by a series of oblique furrows; the medial area corresponds with the upper part of the nucleus of the hypoglossal nerve, the lateral with a small nucleus, termed the *nucleus intercalatus*.

The *sulcus limitans* forms the lateral boundary of the medial eminence. Its superior part corresponds with the lateral limit of the floor and presents a bluish-grey area, named the *locus cæruleus*, which owes its colour to a patch of deeply pigmented nerve-cells termed the *substantia ferruginea*. At the level of the facial colliculus the sulcus limitans widens into a flattened depression, termed the *superior fovea*, and in the inferior part of the floor appears as a distinct dimple termed the *inferior fovea*. Lateral to the foveæ there is a rounded elevation named the *vestibular*

area, which extends into the lateral recess where it forms the *auditory tubercle* (p. 964). Winding round the inferior cerebellar peduncle and crossing the vestibular area and the medial eminence to pass deeply at the median sulcus are a number of white strands termed the *striae medullares* (auditory striae, see p. 964). Below the inferior fovea, and between the hypoglossal triangle and the lower part of the vestibular area, a triangular dark field, named the *vagal triangle* or *trigonum vagi* overlies the dorsal nucleus of the vagus nerve (p. 953). The lower part of the vagal triangle is crossed by a narrow translucent ridge, often named the *funiculus separans*, and between this funiculus and the gracile tubercle is a small tongue-shaped area, which is often termed the *area postrema*. On section it is seen that the funiculus separans is formed by a strip of thickened ependyma, and the area postrema by loose, highly vascular, neuroglial tissue containing nerve-cells of moderate size.

THE MESENCEPHALON OR MID-BRAIN

The **mesencephalon** or **mid-brain** is derived from the intermediate of the three primary cerebral vesicles. In the course of its development in man and in its phylogenetic history it retains a much simpler form than either the fore-brain or the hind-brain. In lower vertebrates the leading feature of the mid-brain is the development in its roof-plate, or *tectum*, of the higher visual (p. 997), and, later, the higher auditory centres. In the mammalia, however, these centres shift forwards to the neopallium, and the importance of the tectum in this respect is correspondingly diminished.

The sulcus limitans develops as in the hind-brain and the spinal medulla, differentiating the basal and the alar laminae. Representatives of the somatic efferent column are present in the form of the nuclei of the third and fourth cranial nerves. In these respects, therefore, the mid-brain shows indications of a primitive metamerism and resembles the medulla oblongata and the tegmental portion of the pons.

With the development of the neopallium of the cerebrum the mid-brain becomes invaded by great tracts of fibres of cortical origin. Some of these form the great new motor-pathway from the cortex, while others are destined to be relayed in the nuclei pontis and constitute cerebro-cerebellar connexions (p. 963). These fibre tracts group themselves on the ventral aspect of the mid-brain on each side of the median plane where they form the base of the cerebral peduncle.

Position and surface form.—The mid-brain passes upwards and forwards through the gap in the tentorium cerebelli and connects the pons and cerebellum (rhombencephalon) with the thalamic, metathalamic and subthalamic regions (diencephalon) and the cerebral hemispheres (telencephalon). It is the shortest segment of the brain-stem, being not more than 2 cm. in length. On each side it is related to the parahippocampal gyrus, which hides its lateral aspect from view when the inferior, or basal, aspect of the brain is examined.

The mid-brain consists of *ventral* and *dorsal portions*, separated from one another in its interior by the cerebral aqueduct, which represents the lumen of the primitive neural tube. The ventral portion consists of the two *cerebral peduncles*, which are separated from each other in front by a deep notch but are continuous with each other behind, across the median plane.

The dorsal portion, or *tectum*, comprises the *colliculi*, which consist of four rounded elevations symmetrically arranged in superior and inferior pairs.

The **cerebral peduncles** emerge from the cerebral hemispheres, one on each side of the median plane, and converge as they descend to disappear into the upper surface of the pons. Curving round each peduncle, close to the upper surface of the pons, a thin white band, named the *tania pontis*, is frequently seen; it enters the cerebellum between the middle and the superior cerebellar peduncles. The depressed area between the diverging cerebral peduncles forms the posterior part of the *interpeduncular fossa* (p. 1019), and consists of a layer of greyish substance, termed the *posterior perforated substance* (p. 1010).

The ventral surface of each peduncle is crossed anteriorly, from the medial to the lateral side, by the superior cerebellar and posterior cerebral arteries, while, close to the point of disappearance of the peduncle into the cerebral hemisphere, the optic tract winds backwards around it. The medial surface of the peduncle is

marked by a longitudinal furrow, termed the *medial sulcus*, from which the roots of the oculomotor nerve emerge (fig. 855). In its upper part it forms the lateral boundary of the interpeduncular fossa. The lateral surface of the peduncle, is in relation with the parahippocampal gyrus of the cerebral hemisphere and is crossed from behind forwards by the trochlear nerve (fig. 859). This surface is marked by a longitudinal furrow, termed the *lateral sulcus*; the fibres of the lateral lemniscus come to the surface in this sulcus, and pass backwards and upwards. Some of them disappear under the inferior colliculus; the remainder enter the inferior brachium.

The **colliculi (corpora quadrigemina)** (fig. 859) are four rounded eminences which form the dorsal part of the mesencephalon. They are situated above and in front of the anterior medullary velum, and below and behind the third ventricle and posterior commissure. They lie below the splenium of the corpus callosum, and are partly overlapped on each side by the pulvinar of the thalamus. The colliculi are arranged in pairs (superior and inferior), and are separated from one another by a cruciform sulcus. The longitudinal part of this sulcus expands superiorly to form a slight depression in which the *pineal body* (fig. 859) lies. From the inferior end of the longitudinal sulcus a white ridge, termed the *frenulum veli*, is prolonged downwards to the anterior medullary velum; at the sides of this ridge the trochlear nerves emerge, and pass forwards on the lateral aspects of the cerebral peduncles to reach the base of the brain. The *superior colliculi* are larger and darker in colour than the inferior, and constitute centres for visual reflexes (p. 1018). The *inferior colliculi*, though smaller, are somewhat more prominent than the superior and are associated with the auditory pathway (p. 995).

From the lateral aspect of each colliculus a white band, termed the *brachium*, is prolonged upwards and forwards. The *superior brachium* extends laterally from the superior colliculus and, passing between the pulvinar and medial geniculate body, is partly continued into an eminence called the lateral geniculate body, and partly into the optic tract. It conducts visual fibres from the retina and from the optic radiation to the superior colliculus. The *inferior brachium* passes forwards and upwards from the inferior colliculus; it conveys fibres from the lateral lemniscus and also from the inferior colliculus to the medial geniculate body.

Internal structure of the mid-brain.—The **cerebral peduncles** (figs. 854, 855).—On transverse section, each peduncle is seen to consist of a dorsal and a ventral part, separated by a deeply pigmented lamina of grey matter, termed the *substantia nigra*. The dorsal part is named the *tegmentum*; the ventral, the *base*. The basal parts of the peduncles are separated from each other, but the tegmenta are continuous with one another across the median raphe. Laterally, the tegmenta are free; dorsally, they blend with the colliculi.

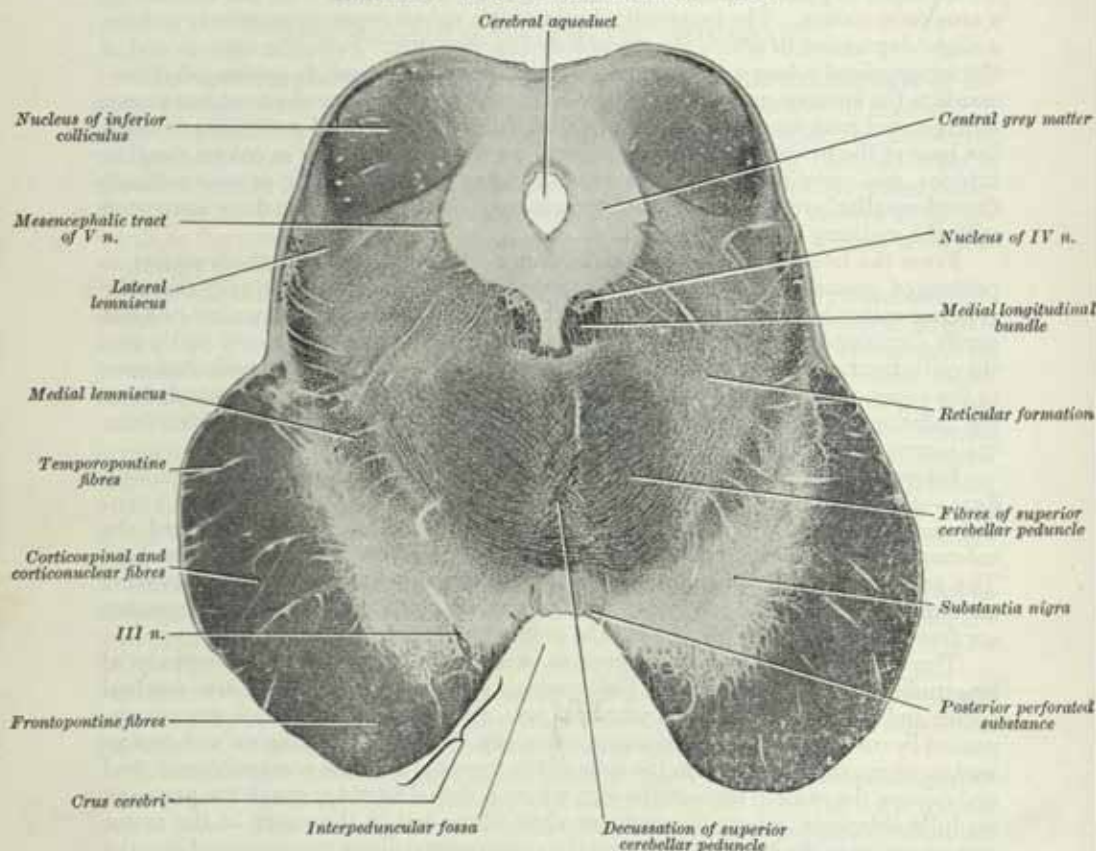
The **base** is semilunar on transverse section, and consists almost entirely of longitudinal bundles of efferent fibres which arise from the cells of the cerebral cortex and are grouped into two principal sets, viz. corticospinal which are accompanied by corticonuclear, and corticopontine, (fig. 854). The *corticospinal* and *corticonuclear* fibres are derived from the cells of the motor area of the cerebral cortex, and occupy the middle three-fifths of the base; they descend through the pons and medulla oblongata, where the corticonuclear fibres end in the nuclei of the motor cranial nerves of the opposite side, but the corticospinal fibres are continued into the pyramid of the medulla oblongata. The corticopontine fibres arise in the cerebral cortex and terminate in the nuclei pontis, where they are relayed to the opposite cerebellar hemisphere. They are subdivided into two main groups: (a) *frontopontine* and (b) *temporopontine*. (a) The frontopontine fibres arise in the frontal lobe, traverse the anterior limb of the internal capsule, and occupy the medial one-fifth of the base of the cerebral peduncle. (b) The temporopontine fibres arise in the temporal lobe, traverse the posterior limb of the internal capsule and occupy the lateral one-fifth of the base of the cerebral peduncle; they end in the nuclei of the pons.*

* A band of fibres, named the *tractus peduncularis transversus*, is sometimes seen emerging from the optic tract on the lateral aspect of the cerebral peduncle; it passes round the ventral surface of the peduncle about midway between the pons and the optic tract, and disappears by entering the interpeduncular fossa behind and lateral to the corpus mamillare, where it terminates in a small nucleus. This band is a constant structure in many mammals, but is only present in about thirty per cent. of human brains. Since it undergoes atrophy after enucleation of the eyeballs, it may be considered as being associated with the visual pathway.

Parieto- and occipitopontine fibres accompany the temporopontine fibres through the base of the cerebral peduncle.*

The **substantia nigra** is a lamina of grey matter containing numerous, deeply pigmented, multipolar nerve-cells and extending throughout the whole length of the mid-brain. Owing to its pigmentation it can readily be recognised with the naked eye on transverse or coronal sections (fig. 860) of this part of the brain-stem. It is semilunar on transverse section, its concavity being directed towards the tegmentum; from its convex surface, processes extend between the fibres of the base of the peduncle. Thicker medially than laterally, it reaches from the medial to the lateral sulcus, and extends from the upper surface of the pons to the subthalamic region; its medial part is traversed by the fibres of the oculomotor nerve as they stream forwards to reach the oculomotor

FIG. 854.—Transverse section through the mid-brain at the level of the inferior colliculus. Weigert Pal preparation. $\times 4.1$.



sulcus. The fibre connexions and the functions of the substantia nigra are still obscure. Its structure includes both large and small nerve-cells, and it is believed to form a part of the extrapyramidal system (p. 1076). Numerous connexions have been described, including *afferent fibres* from the motor and premotor areas of the cortex, the caudate nucleus,† the globus pallidus and the red nucleus. *Efferent fibres* enter the tegmentum but their ultimate destination, though probably the motor cells of the anterior grey column of the spinal medulla, has not been established. Stimulation of the substantia nigra causes increased extensor tonus. In addition, efferent fibres to the globus pallidus and to the thalamus have been described.‡ The substantia nigra is relatively small in lower mammals, and contains no pigment.

* J. W. Papez and R. W. Rundles, *Arch. Neurol. Psychiat.*, 38, 1937.

† S. Sunderland, *J. Anat.*, Lond., 74, 1940.

‡ P. Glees and P. D. Wall, *Brain*, 69, 1946.

The **tegmentum** of the mid-brain presents appearances which differ according to the level of the section examined. Below, it is directly continuous with the tegmentum of the upper part of the pons and contains the same fibre tracts.

A. In its *lower part*, i.e. on a level with the inferior colliculi, the grey matter is restricted to the immediate environs of the cerebral aqueduct and to the scattered collections in the reticular formation (fig. 854).

The **nucleus of the trochlear (fourth cranial) nerve** lies in the ventral part of the central grey matter, close to the median plane. It occupies a position homologous with that occupied by the abducent and hypoglossal nerves at lower levels in the brain-stem. Closely related throughout its extent to the medial longitudinal bundle, which lies on its ventral aspect, the nucleus extends through the lower half of the mid-brain, and its upper limit lies just below the lower limit of the oculomotor nucleus. Its *outgoing fibres* pass laterally and backwards round the central grey matter. Inclining downwards, they decussate with each other immediately below the inferior colliculi and emerge from the dorsal aspect of the anterior medullary velum (fig. 859).

The unusual course of the outgoing fibres, their decussation and their emergence on the dorsal aspect of the brain-stem, are very difficult to explain.* The fact that in the embryo the trochlear nucleus is at first separated from the oculomotor nucleus by a distinct gap and later migrates headwards into the mid-brain until it reaches the caudal end of the oculomotor nucleus, indicates that the region of the isthmus rhombencephali is unstable. Frazer has suggested that the isthmus is partly 'telescoped' into the mid-brain, and that during this process the basal lamina extends laterally over the inner surface of the alar lamina, carrying the point of emergence of the trochlear nerve with it. The same author suggested, on the analogy of the ventral nerve-roots of the spinal nerves, which possess a large ipsilateral and a small contralateral component, that the trochlear nerve possesses a large contralateral and a small ipsilateral component.

The **nucleus of the mesencephalic tract of the trigeminal nerve** lies in the lateral part of the central grey matter. This nucleus is composed of a column of pseudo-unipolar and multipolar cells; it extends from the upper end of the main sensory nucleus of the trigeminal nerve in the pons to the level of the superior colliculus in the midbrain. It is accompanied by a tract composed of the peripheral and central branches of the axons of its cells. It is believed that the peripheral branches convey proprioceptive impulses from the muscles of mastication and it is also alleged that proprioceptive impulses travel to the mesencephalic nucleus from the teeth and from the facial and ocular muscles.†

Apart from these two nuclei the central grey matter at this level contains large numbers of scattered nerve-cells, the significance of which is unknown. Irregular collections of grey matter occur in the reticular formation, especially in the region immediately above the pons (see also p. 954). These are regarded as relay stations on the extra-pyramidal pathway, and their efferent fibres pass to the reticular formation of the pons and medulla oblongata, to the motor nuclei of the cranial nerves, to the olivary nucleus and to the anterior grey column of the spinal medulla. The position of these *tegmentospinal* fibres in the spinal medulla is not known.

The **white matter** at this level of the mid-brain contains all the tracts which have already been examined in the tegmentum of the pons, and it is characterised by the great decussation of the fibres of the superior cerebellar peduncles.

* In all vertebrates the trochlear nerves behave in the same peculiar way. Nevertheless it would appear to be certain that in some unknown ancestral form the trochlear nerves, like the oculomotor, abducent and hypoglossal nerves, emerged from the ventrolateral aspect of the brain-stem. It has been suggested that the trochlear nerve originally supplied the muscles of the pineal eye, and this would offer an explanation for the course of the fibres in a dorsal direction. The position of the nerve within the mid-brain medial to the nucleus of the mesencephalic tract of the trigeminal nerve may possibly be associated with the history of the nucleus, which is generally regarded as a derivative of the neural crest, secondarily included in the substance of the brain-stem. If, prior to the inclusion of the nucleus, the trochlear nerve passed dorsally across the side of the brain-stem to reach the muscles of the pineal eye, it too would necessarily be included in the process. The decussation of the trochlear nerves presents a further difficulty, but it might possibly be ascribed to changes affecting the disposition of the muscles of the primitive pineal eye. It must be admitted, however, that these explanations are in the highest degree speculative.

† K. B. Corbin and F. Harrison, *J. Neurophysiol.*, 3, 1940. E. P. Stibbe, *J. Anat.*, Lond., 64, 1929. H. H. Woollard, *J. Anat.*, Lond., 65, 1931 and A. A. Pearson, *J. Comp. Neurol.*, 90, 1949.

The *superior cerebellar peduncle*, which has already been described (p. 975), enters the dorsilateral part of the tegmentum and passes forwards and medially round the central grey matter to reach the median raphe, where it decussates with its fellow of the opposite side. Having crossed the median plane, the fibres divide into ascending and descending branches; some of the former terminate in the red nucleus, which they encapsulate (fig. 865), but numerous others are continued upwards and end in the ventral nucleus of the thalamus.

The *medial longitudinal bundle* retains its intimate relationship to the somatic efferent column, and therefore lies dorsal to the decussating fibres of the superior cerebellar peduncles.

The *medial lemniscus* forms a curved band lying dorsal to the lateral part of the substantia nigra. Laterally the tract is closely related to the lateral lemniscus, which is ascending with a backward inclination to reach the inferior colliculus. Thereafter it continues upwards, in intimate relation with the spinal and trigeminal lemnisci, traverses the subthalamic region and terminates in the caudal part of the ventral nucleus of the thalamus (p. 1002). There the third neurone fibres begin and they ascend through the internal capsule (p. 1063) to reach the cortex of the postcentral gyrus (p. 1044).

The *lateral lemniscus* is formed in the tegmentum of the pons by the fibres issuing from the corpus trapezoideum and by fibres from the nucleus of the lateral lemniscus and from the vestibular nuclei. The nucleus of the lateral lemniscus is interposed in the path of the lateral lemniscus as it ascends through the lateral part of the tegmentum (p. 969). The fibres of the lateral lemniscus incline dorsally as they run up through the tegmentum of the mid-brain and come to lie on its lateral surface immediately behind the lateral sulcus. Passing superficial to the superior cerebellar peduncle, they reach the inferior colliculus, in which some of them terminate, and are relayed in the inferior brachium to the medial geniculate body, while others pass direct to the inferior brachium and end in the medial geniculate body. According to some observers the fibres of the lateral lemniscus divide into medial and lateral branches. The former terminate in the inferior colliculus, but the latter are continued into the inferior brachium, by which they are conducted to the medial geniculate body.

The fibres of the *spinal* and *trigeminal lemnisci* are indistinguishable from the fibres of the dorsilateral portion of the medial lemniscus, with which they ascend to the thalamus.

B. In its *upper part* the tegmentum presents the same general plan, but it is strikingly modified by the appearance of a large nucleus, which extends upwards into the subthalamic region and is termed the *red nucleus*.

The *central grey matter* surrounds the aqueduct and contains in its ventrimedial portion the *nucleus of the oculomotor nerve*. This sausage-shaped nucleus is closely related on its ventral aspect to the medial longitudinal bundle, and inferiorly it extends to the upper end of the trochlear nucleus (fig. 854).

The nucleus of the oculomotor nerve is divisible into a number of cell-groups which can be correlated with the motor distribution of the nerve. They include the Edinger-Westphal nucleus and are all described on p. 1096.

The *nucleus of Darkschewitsch* is a large-celled nucleus which lies dorsilateral to the upper end of the oculomotor nucleus in the central grey matter. It sends efferent fibres into the medial longitudinal bundle and also into the posterior commissure, but its functional significance is unknown.

The *red nucleus* is a large, ovoid mass of grey matter which occupies most of the medial part of the tegmentum of the upper half of the mid-brain, and extends upwards into the subthalamic region. Ventrally it is related to the substantia nigra, from which it is only separated by some of its surrounding fibres. Laterally it is related to the medial lemniscus; dorsally it is separated from the central grey matter by the *formatio reticularis*, here very much reduced in area, and the medial longitudinal bundle. On its medial side, the fibres by which it is surrounded, the *fasciculus retroflexus* (fig. 865) and the outgoing oculomotor nerve separate the nucleus from the median raphe and the ventral and dorsal tegmental decussations. It is not homogeneous in structure, and the cells of the upper two-thirds, which are small in size, bear no resemblance to the large cells which are found in its lower third.

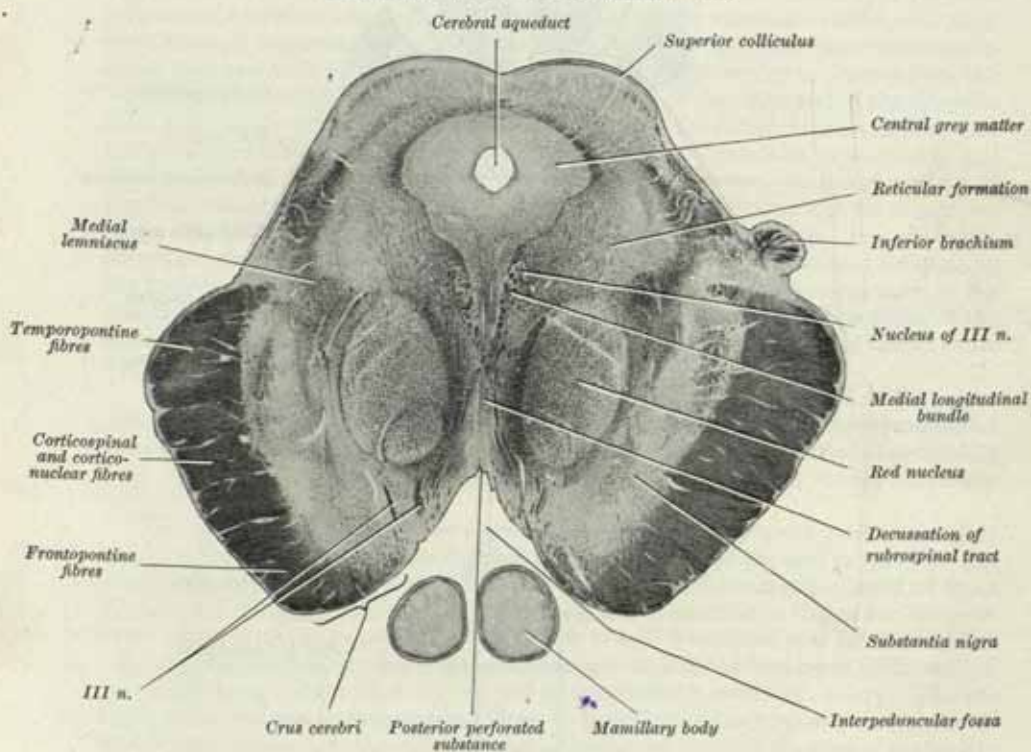
Afferent fibres reach the red nucleus from the superior cerebellar peduncle, and

the globus pallidus of the lentiform nucleus (pallidorubral fibres),* the subthalamic nucleus, and, possibly, direct from the cerebral cortex. The origin of the cortical fibres has been variously ascribed to the frontal, temporal and parietal lobes.

The *efferent* fibres from the red nucleus connect it with (1) the anterior column of the grey matter of the spinal medulla (rubrospinal tract), (2) the nuclei of the reticular formation of the pons and the medulla oblongata (rubroreticular tract), (3) the substantia nigra and (4) the thalamus.

The red nucleus constitutes an important cell-station on the extrapyramidal system (p. 1076) and therefore plays a part in the nervous mechanism of movements. It is connected to the anterior column of the grey matter of the spinal medulla by the rubrospinal tract, but it is unlikely that this is the principal pathway involved, for although the rubrospinal tract is a large bundle in many lower mammals, it is relatively small in man. It is possible that the rubroreticular tract, which is relatively large in man, may transmit impulses from the corpus striatum and also,

FIG. 855.—Transverse section through the mid-brain at the level of the superior colliculus. Weigert Pal preparation. $\times 3$.



perhaps, from the cerebellum, through a series of relay stations in the reticular formation in the hind-brain to the spinal medulla.

Phylogenetically the large-celled part of the red nucleus is older than the small-celled part. In lower animals the former forms the greater portion of the nucleus but in man it is the latter. The small-celled portion of the nucleus becomes developed and elaborated *pari passu* with the expansion of the cerebellar hemispheres and the frontal lobes of the cerebrum, with which, according to Monakow, the red nucleus is freely connected.

The white matter of the tegmentum at this level shows certain local modifications, chiefly in the region of the median raphe.

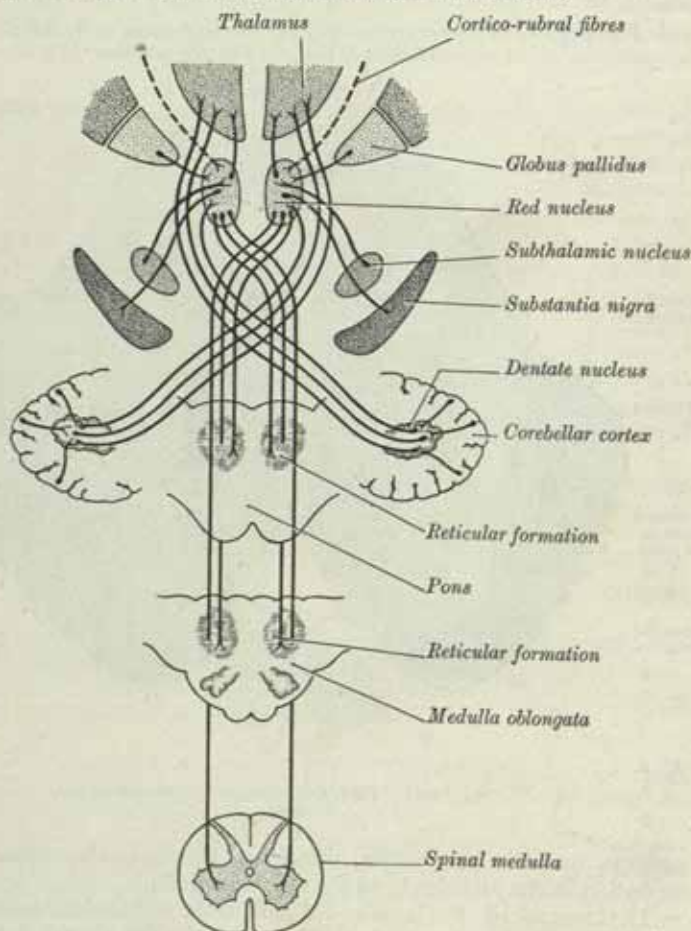
The *rubrospinal tract* takes origin at this level from the large cells in the lower part of the red nucleus. The fibres at once pass to the median raphe and there decussate in its ventral portion with the corresponding fibres of the opposite side, forming the *ventral tegmental decussation*. They then pass downwards in front of the decussation of the superior cerebellar peduncles and descend in the formatio

* S. W. and M. Ranson, *Anat. Rec.*, 79, Suppl., 1941.

reticularis of the pons and medulla oblongata. Finally they enter the spinal medulla, lying on the ventrolateral aspect of the lateral corticospinal tract, and terminate by arborising round the cells in the anterior column of the grey matter. It is believed that in man the rubrospinal tract extends only to the thoracic region of the spinal medulla.

The *tectospinal* and the *tectobulbar tracts* also take origin at this level. Their fibres arise in the grey matter of the superior colliculi and sweep forwards round the central grey matter to decussate with one another in the median raphe ventral to the oculomotor nucleus and the medial longitudinal bundle, forming the dorsal tectal decussation. Emerging from this decussation the tectospinal tract descends on the ventral aspect of the medial longitudinal bundle as far as the decussation of the medial lemniscus in the medulla oblongata. Thereafter it diverges ventri-

FIG. 856.—A diagram to show the connexions of the red nucleus.



laterally and in the spinal medulla it lies in the lateral column in front of the rubrospinal tract.* The tectobulbar tract, which may be divided into a dorsal, crossed tract, and a ventral, uncrossed tract, descends through the reticular formation of the mid-brain and the pons and terminates by sending its fibres into the oculomotor, trochlear, abducent and accessory nuclei. It serves as a pathway for reflex movements of the eyes in response to visual stimuli.

The *medial longitudinal bundle* lies on the ventrolateral aspect of the oculomotor nucleus. At this level its fibres are more spread out than they are at lower levels in the brain-stem, but the intimate relationship to the efferent nuclei is retained. The bundle extends upwards to the *interstitial nucleus*—a small collection

* See footnote * on p. 941 and † on p. 942.

of cells situated in the lateral wall of the third ventricle immediately above the upper end of the cerebral aqueduct—which contributes fibres to it. As has already been seen, the medial longitudinal bundle retains its position relative to the central grey matter throughout the whole extent of the mid-brain, pons and the upper part of the medulla oblongata. It is displaced forwards by the successive decussations of the medial lemnisci and the lateral corticospinal tracts, and becomes continuous with the anterior intersegmental fasciculus of the spinal medulla.

The intimate relationship which it bears successively to the nuclei of the third, fourth and sixth cranial nerves, to the emerging fibres of the seventh, the fibres from the dorsal cochlear nucleus in the floor of the fourth ventricle and the nucleus of the twelfth nerve renders it a very convenient pathway for the passage of fibres from one nucleus to another in the brain-stem. The harmonious co-operation obviously existing between the facial nerves and the hypoglossal nerves in the movements of the lips and tongue in speech is frequently attributed to connexions between their nuclei conveyed by the medial longitudinal bundle. It is, however, very doubtful whether it is the medial longitudinal bundle which provides the pathway for these connexions. Edinger, Winkler and others have shown that the most substantial contributions to the bundle are made by the vestibular nuclei, and their work strongly suggests that its chief function is to ensure the co-ordinate movements of the eyes and head in response to stimulation of the eighth nerve. Fibres from the vestibular nuclei (superior, lateral and medial), both of the same and of the opposite side, join the bundle, where they ascend, descend or divide into ascending and descending branches. These vestibular fibres send collaterals to, or they may end in, the nuclei of the third, fourth and sixth cranial nerves and the spinal nucleus of the eleventh nerve (fig. 857). In addition, fibres join the bundle from the dorsal nucleus of the corpus trapezoidum and the nucleus of the lateral lemniscus. It is probable, therefore, that the cochlear as well as the vestibular nerve is capable of influencing the movements of the eyes and head through the bundle. The continuity of the bundle with the anterior intersegmental tract offers a pathway to those nuclei of the spinal medulla which innervate the rotator muscles of the head and neck, other than the sternocleidomastoid.

The *inferior brachium* forms a rounded strand on the lateral aspect of the upper part of the mid-brain (fig. 863). Its fibres are derived from the inferior colliculus and from the lateral lemniscus and they are ascending to reach the medial geniculate body. In their course they separate the dorsilateral fibres of the medial lemniscus from the surface.

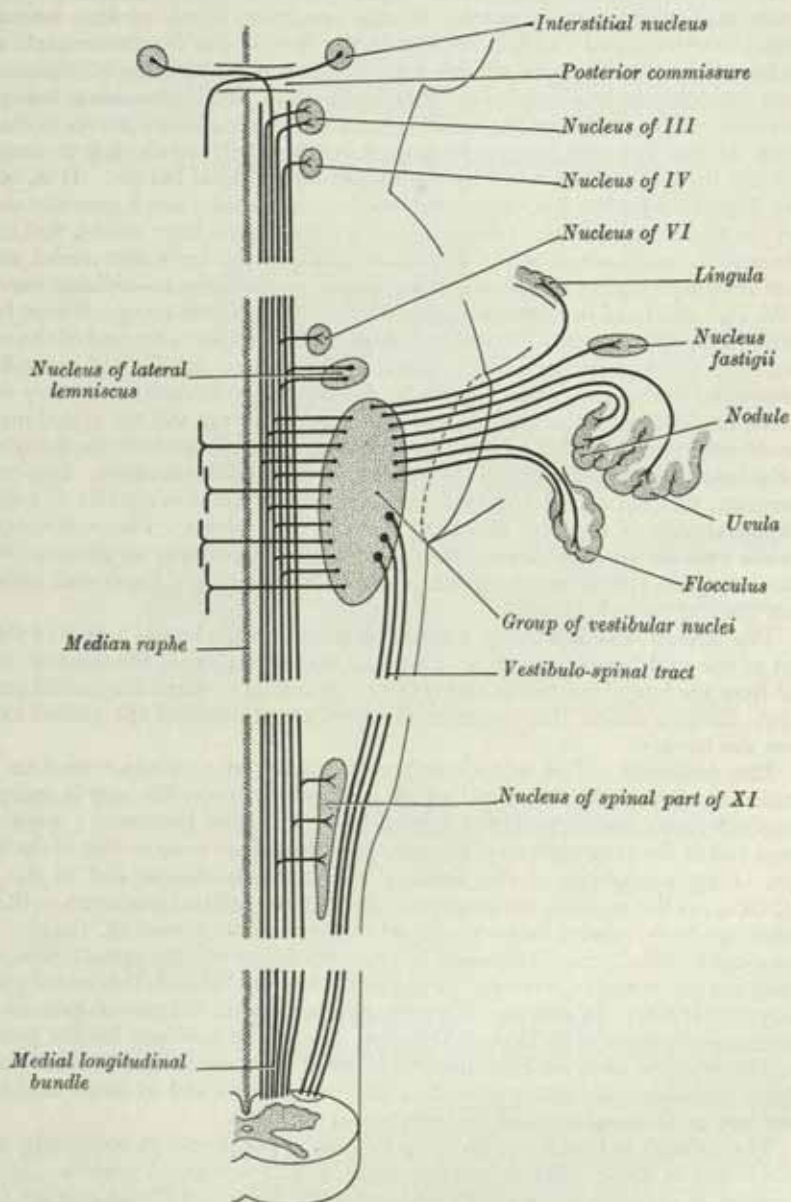
The colliculi.—The *inferior colliculus* consists of a compact nucleus of grey matter which contains large and small multipolar nerve-cells, and is more or less completely surrounded by fibres derived from the lateral lemniscus; most of these fibres end in the grey nucleus of the same side, but some cross to that of the opposite side. Only a minority of the fibres of the lateral lemniscus end in the inferior colliculus, as the majority are continued through the inferior brachium to the medial geniculate body, where they are relayed to the auditory cortex (p. 1047). The inferior colliculus sends commissural fibres to its fellow of the opposite side, some of which are continued on through the inferior brachium to reach the medial geniculate body of that side. In addition, it sends efferent fibres to the medial geniculate body and to the superior colliculus, of the same side. The evidence for the presence of the last group is entirely experimental* and if they are in fact present—as seems highly probable—the fibres must be finely medullated and of small calibre, since they cannot be demonstrated by histological methods.

The inferior colliculus reaches its highest development in mammals, and it is only found in those animals which possess a well-developed cochlea. It is to be regarded as a centre for auditory and, possibly, some vestibular reflexes (p. 965), which are probably mediated through the tectospinal and tectobulbar tracts.* There is no evidence that it functions as a relay station on the path to the cerebral cortex. In this connexion it should be observed that many of the fibres of the lateral lemniscus divide into medial and lateral branches which are distributed to the inferior colliculus and the medial geniculate body, respectively.

The *superior colliculus* is covered by a thin stratum of white fibres, which constitute the *stratum zonale*. Beneath this the *stratum cinereum* forms a cap-like layer

of grey matter, thicker in the centre than at the circumference, and consisting of numerous small multipolar nerve-cells imbedded in a fine network of nerve-fibres. Still deeper is the *stratum opticum*, containing large multipolar nerve-cells separated

FIG. 857.—A diagram to show the principal fibre groups which contribute to the formation of the *medial longitudinal bundle*. The distribution of its fibres to the nuclei of III, IV, VI and XI is also shown.



Note.—To avoid over-complication of the figure, the posterior nucleus of the corpus trapezoidum and its contribution to the bundle (p. 967) are omitted.

by numerous fine nerve-fibres. Finally, there is the *stratum lemnisci*, consisting of fibres, many of which are derived from the medial lemniscus; others are commissural and derived from the cells of the stratum opticum; many large multipolar nerve-cells are interspersed among these fibres.

Afferent fibres reach the superior colliculus from the following sources: (1)

fibres originating in the retina and conveyed by the superior brachium; (2) fibres arising in the visual cortex of the occipital lobe and travelling by the optic radiation to the superior brachium; (3) fibres arising in the spinal medulla and ascending in the spinotectal tract; (4) fibres arising in the inferior colliculus of the same side (see above) and forming the afferent pathway for auditory reflexes.

Efferent fibres take part in the dorsal tegmental decussation and constitute the tectobulbar and the tectospinal tracts (p. 994), which establish connexions with the motor nuclei of the third, fourth, sixth and eleventh cranial nerves, and the anterior column cells of the spinal medulla. Others cross the median plane to reach the superior colliculus of the opposite side, while still others have been described as entering the medial longitudinal fasciculus.

In fishes, reptiles and birds the tectum is occupied by the *optic lobes*, which represent the superior colliculi of mammals. They not only function as the highest visual centres but they also play an important part in connexion with the control of muscular movements. In these animals the cerebral cortex, the corpus striatum (p. 1064) and the cerebellum do not respond to electrical stimulation, which produces motor responses only when applied to the optic lobes.* In mammals, however, the evolution of the visual cortex and of the motor cortex has resulted in a diminution of the importance of these centres, and most of the fibres of the optic tracts avoid them and are relayed in the lateral geniculate bodies on their way to the higher centres. The superior colliculus continues to receive some fibres from the optic tract, but the significance of this connexion is uncertain. In addition the superior colliculus receives afferent fibres from the visual cortex, the impulses from which are relayed to the tectobulbar and tectospinal tracts. In the lower vertebrates these tracts appear to function as the principal motor pathways, but in mammals they provide a pathway for reflex movements of the musculature of the eyes, head and neck which may be necessitated by visual impressions.

The *pretectal nucleus* is a circumscribed collection of grey matter which lies deep to the upper and lateral part of the superior colliculus and projects upwards to a slightly higher level. Through the superior brachium it receives *afferent fibres* from (1) the lateral root of the optic tract † and (2) the occipital cortex adjoining the striate area. Its *efferent fibres* pass medially dorsal to the cerebral aqueduct and then curve forwards round the central grey matter to reach the Edinger-Westphal nucleus (p. 1096) from which fibres are relayed to the oculomotor nerves of both sides.‡ The pretectal nucleus constitutes an essential element in the pathway for the light reflex (fig. 871).

The *cerebral aqueduct (aqueduct of the mid-brain)* is a narrow canal, about 15 mm. long, situate between the colliculi and tegmentum, and connecting the third with the fourth ventricle. Its form, as seen in transverse sections, varies at different levels, being T-shaped below, triangular above, and oval in the middle; its central part is slightly dilated. It is lined with ciliated columnar epithelium, and is surrounded by a layer of grey matter named the *central grey stratum*; this is continuous below with the grey matter in the floor of the fourth ventricle, and above with that of the third ventricle. Dorsally the aqueduct is partly separated from the grey matter of the colliculi by the fibres of the stratum lemnisci; ventral to it are the medial longitudinal bundle, and the formatio reticularis of the tegmentum. Scattered throughout the central grey stratum are numerous nerve-cells of various sizes, interlaced by a network of fine fibres. Besides these scattered cells it contains three groups, which constitute the nucleus of the mesencephalic tract of the trigeminal nerve and the nuclei of the oculomotor and trochlear nerves (pp. 991 and 992).

THE FORE-BRAIN OR PROSENCEPHALON

The *fore-brain* or *prosencephalon* consists of: (1) the *diencephalon*, corresponding in a large measure to the third ventricle and the structures which bound it; and (2) the *telencephalon*, comprising the largest part of the brain, viz. the cerebral hemispheres; these hemispheres are connected with each other across the median

* A. A. Abbie, *Essays in Biology*, Burkitt Memorial Volume, 1948.

† K. G. Lashley, *J. Comp. Neurol.*, **59**, 1934.

‡ R. L. Crouch, *J. Comp. Neurol.*, **64**, 1936.

plane, and each contains an extensive cavity, named the lateral ventricle. The lateral ventricles communicate with each other and with the third ventricle through the interventricular foramina, and are separated from each other over a wide area only by a median septum, termed the septum pellucidum; this contains a slit-like cavity, which does not communicate with the ventricles.

THE DIENCEPHALON

Introductory.—The **diencephalon** is derived from the caudal end of the fore-brain. In the human embryo and in all vertebrates it is situated cranial to the cranial end of the notochord, and it may therefore be regarded as an extension of the brain beyond the limits of the primitive segments of the body. It may be expected that the imprints of metamerism and branchiomerism, which have been observed in the brain-stem and spinal medulla, will no longer be found in the diencephalon.

The lateral walls of this portion of the embryonic neural tube undergo enormous thickening and form two large nuclear masses, which are termed the *thalami*. They are the largest and most important of all the derivatives of the diencephalon. In primitive vertebrates they constitute the highest centres for the correlation of all sensory impressions but, with the evolution of the neopallium, they become relegated to a position of less importance, acting as relay stations on the sensory pathway to the cortex. Although they are no longer the dominant factor in determining behaviour they do retain a large measure of their earlier importance, for their countless connexions with the whole of the cortex, as well as with the corpus striatum and the cerebellum, indicate that they play an active and essential part in all cortical activities. In addition, it would appear that sensory impressions can reach consciousness in the thalami when their cortical connexions have been severed.

Caudal to the thalamus two elevations appear on the lateral aspect of the diencephalon, and they can be recognised at first on the inner wall as two hollowed-out areas. They form the medial and lateral geniculate bodies, which together constitute the *metathalamus*. As the thalamus enlarges it extends tailwards and, growing backwards so as to overhang the mid-brain, intervenes between the geniculate bodies and the cavity of the diencephalon. The medial geniculate body has already been seen in the groove between the lateral aspect of the mid-brain and the overhanging posterior end of the thalamus, while the lateral geniculate body comes to lie in close contact with the inferior aspect of the posterolateral part of the thalamus and appears to be incorporated in it.

The roof-plate of the diencephalon retains its epithelial character throughout the greater part of its extent and forms, in the adult, the *ependymal roof of the third ventricle*. At its posterior (or caudal) end the roof and the adjoining portions of the lateral walls give rise to a number of structures, which together constitute the *epithalamus*. A collection of cells in this part of the lateral wall forms the *habenular nucleus*, which sends its fibres across the median plane, through the roof-plate, to constitute the *habenular commissure*. More caudally a second commissural bundle invades the roof, and is termed the *posterior commissure*. In the interval between these two commissures a hollow diverticulum grows backwards in the median plane. This is termed the *epiphysis*. In many reptiles it gives off a second process, which arises from the anterior wall of its base and constitutes the pineal or parietal eye (p. 1009). This organ has been identified in the human embryo, but it does not persist; the epiphysis, on the other hand, which forms a hollow glandular structure in reptiles, secreting directly into the third ventricle, becomes converted into a solid organ, termed the *pineal body*.

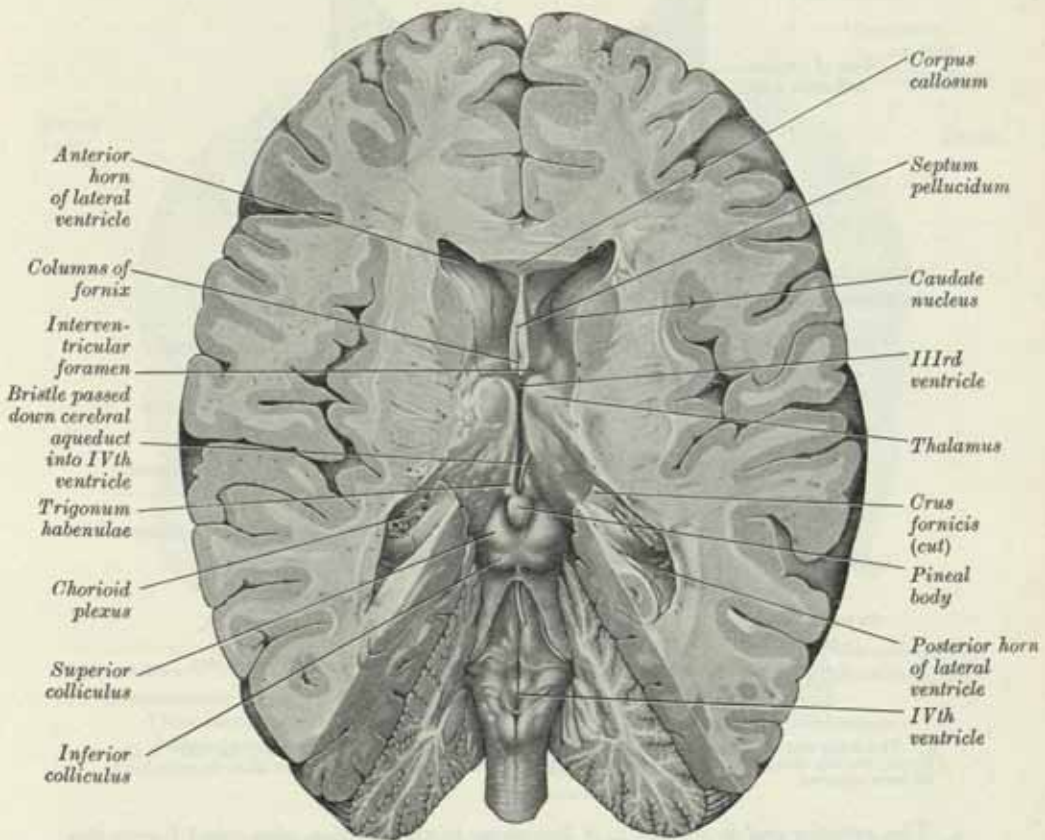
We have seen how the thalamus, the metathalamus, the epithalamus and a large part of the roof of the third ventricle are derived from the diencephalon. The parts which have still to be considered are derived from the ventral portions of its lateral walls and from its floor. They contribute to the formation of the *hypothalamus*, forming the subthalamic region, the corpora mamillaria, the tuber cinereum, and the infundibulum, but the most anterior part of the hypothalamus, which includes the optic chiasma and the lamina terminalis, is derived from the telencephalon.

The *subthalamic region* is the upward continuation of the tegmentum, and lies immediately below the thalamus. The mamillary bodies form as a median thickening in the floor of the diencephalon, which is subsequently divided into two by a median groove. They are an important cell-station in connexion with the activities

of the autonomic system (p. 1002). The area in front of them forms the tuber cinereum. This area is very highly developed in those fishes in which the olfactory is dominated by the gustatory sense, but it undergoes marked reduction in air-breathing vertebrates.

The *infundibular process* arises as a hollow outgrowth from the floor of the diencephalon which subsequently loses its cavity and becomes converted into a solid mass of cells to form the posterior lobe of the hypophysis. The stalk which connects the hypophysis to the floor of the third ventricle forms the infundibulum, and it retains its hollow character in the adult. It will be remembered that the anterior lobe of the hypophysis develops as a hollow diverticulum from the roof of the primitive mouth (p. 185), and it is probable that in some ancestral vertebrates there was a bucconeural duct, such as occurs in larval ammocetes. Such a duct

FIG. 858.—The ventricles of the brain. Exposed from above and behind.



The splenium and most of the trunk of the corpus callosum have been removed; the body of the fornix and most of the tela chorioidea have been excised, together with portions of the occipital lobes and the cerebellum. A bristle has been passed from the third ventricle through the cerebral aqueduct into the fourth ventricle.

provided for the passage of water from the mouth to the neural tube and afforded the possibility of a water-vascular circulation for the central nervous system. In all reptiles and amphibia the infundibular process remains hollow, but in nearly all mammals it becomes a solid body and forms, as in man, the posterior lobe of the hypophysis.

The *optic chiasma* is developed in association with the optic nerves (p. 147). In all vertebrates the fibres of the optic nerves decussate, either completely or partially, in the floor of the fore-brain, and constitute the optic chiasma (p. 1015).

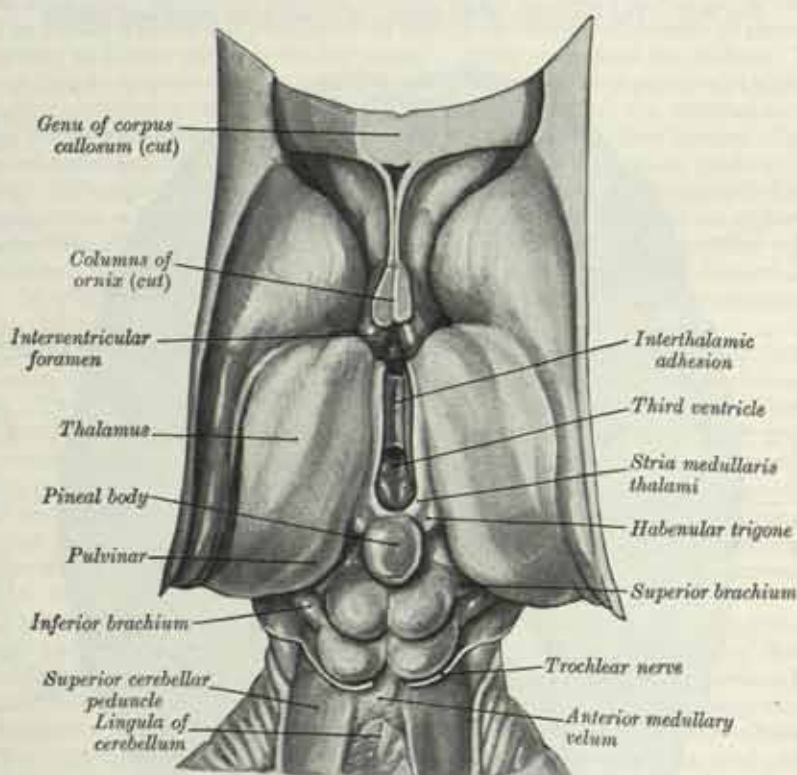
The *lamina terminalis* is the cephalic end of the neural tube and, in view of the development of the roof and floor of this part of the telencephalon, it forms the one

area where large and important commissural connexions between the cerebral hemispheres are able to develop.

Parts derived from the diencephalon.—The diencephalon comprises the thalamus, metathalamus and epithalamus (which together constitute the *thalamencephalon*), and most of the hypothalamus, but these structures include so many of the boundaries of the third ventricle of the brain that it will be convenient to describe the anterior part of the hypothalamus and the third ventricle as a whole in this section, together with the true derivatives of the diencephalon.

The **thalami** (figs. 859, 860) are two large ovoid masses of grey matter, situated one on each side of the third ventricle and reaching for some distance behind that cavity. Each thalamus is about 4 cm. long, and has two ends and four surfaces.

FIG. 859.—The thalami exposed from above.



The trunk and splenium of the corpus callosum, most of the septum pellucidum, the body of the fornix, the tela chorioides with its contained plexuses and the epithelial roof of the third ventricle have all been removed.

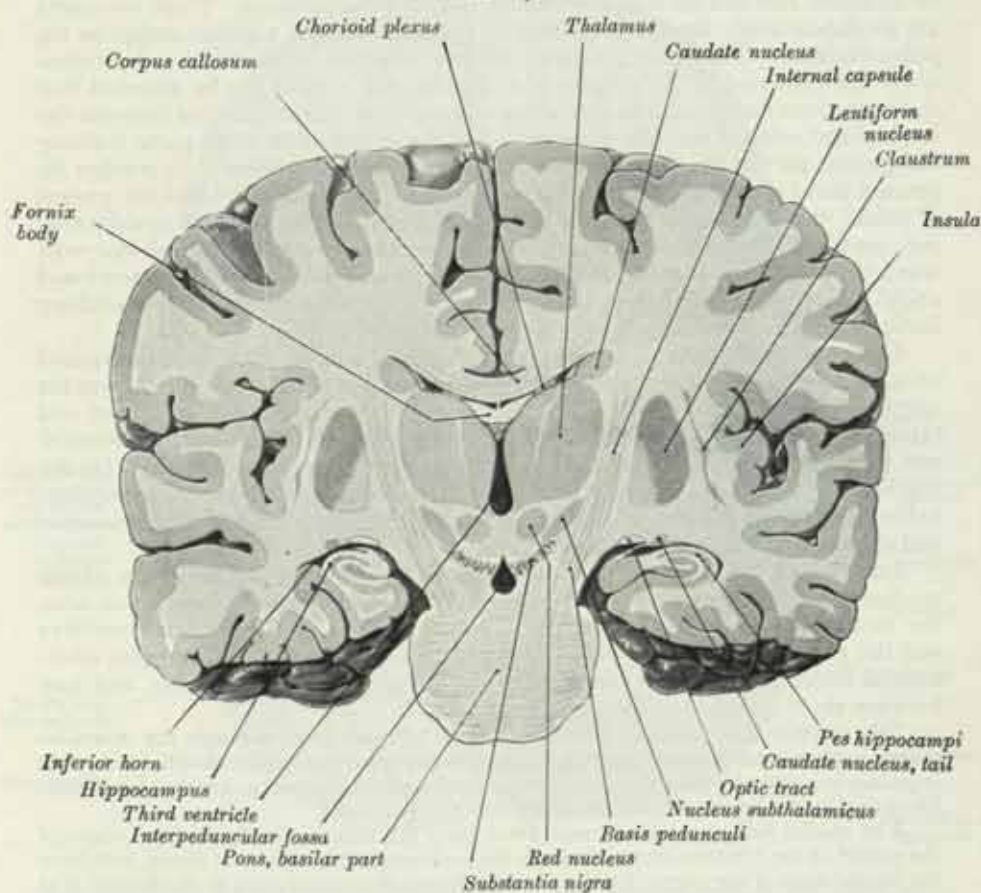
The *anterior end* is narrow; it lies close to the median plane and forms the posterior boundary of the interventricular foramen.

The expanded *posterior end*, which is termed the *pulvinar*, is directed backwards and laterally and overhangs the superior colliculus and the superior brachium. The lateral geniculate body (p. 1006) forms a small, oval elevation on the inferior aspect of its lateral part. Inferiorly, the pulvinar is separated from the medial geniculate body (p. 1006) by the superior brachium.

The *superior surface* (fig. 859) is free, slightly convex, and covered by a layer of white matter, termed the *stratum zonale*. It is separated laterally from the ventricular surface of the caudate nucleus by a white band, termed the *stria terminalis*, and by the thalamostriate vein (p. 846). It is divided into a lateral and a medial portion by an oblique shallow furrow, which runs from behind forwards and medially from the lateral part of the posterior end to the anterior part of the medial border; this furrow corresponds with the lateral margin of the body of the fornix. The lateral part forms a portion of the floor of the lateral ventricle. It is covered with the epithelium of that cavity, and is partly hidden by the vascular fringe of the

chorioid plexus (fig. 860). The medial part of this surface is covered with the tela chorioidea of the third ventricle, by which it is separated from the body of the fornix. Between the lateral edge of the fornix and the upper surface of the thalamus the lateral margin of the tela chorioidea with its contained plexus is invaginated into the ventricle through the chorioid fissure (fig. 909). In front, the superior surface is separated from the medial surface by a narrow, raised ridge from which the epithelial lining of the third ventricle is reflected to the under surface of the tela chorioidea. This ridge covers a small bundle of white fibres, named the *stria medullaris thalami* (p. 1008). Posteriorly it turns medially to form the anterior

FIG. 860.—A coronal section through the brain at the anterior part of the pons. Posterior aspect.



boundary of the *trigonum habenulae* (fig. 859), from which the upper surface of the thalamus is separated by the *sulcus habenulae*.

The *inferior surface* rests upon and is continuous with the upward prolongation of the tegmentum (*subthalamic tegmental region*) (fig. 860).

The *medial surface* (fig. 870) constitutes the upper part of the lateral wall of the third ventricle; it is connected to the corresponding surface of the opposite thalamus by a flattened grey band, named the *interthalamic adhesion* (*connexus interthalamicus*). This band lies close behind the interventricular foramen, and averages about 1 cm. in its anteroposterior diameter; it sometimes consists of two or even three parts, and occasionally is absent. It contains nerve-cells and nerve-fibres; a few of the latter may cross the median plane, but most of them pass towards the median plane and then curve laterally on the same side. This surface of the thalamus is limited below by a curved groove, often ill-defined, termed the *hypothalamic sulcus*. It curves upwards and forwards from the upper end of the cerebral aqueduct to the floor of the interventricular foramen and is usually regarded as the upward continuation of the *sulcus limitans* of the spinal medulla and brain-stem.

On its *lateral surface* there is a thick band of white substance consisting of projection fibres which form the posterior limb of the internal capsule and separate the thalamus from the lentiform nucleus of the corpus striatum (fig. 86o).

Structure.—The thalamus consists chiefly of grey matter, but its upper surface is covered by a layer of white matter, named the *stratum zonale*, and its lateral surface by a similar layer, termed the *external medullary lamina*. Its grey matter is incompletely subdivided into three parts—*anterior*, *medial*, and *lateral**—by a vertical white layer, the *internal medullary lamina* (fig. 86o).

The *anterior part* † comprises the anterior end or tubercle of the thalamus and its flattened and tapered posterior end lies on the superior surface of the medial and lateral parts. It contains the anterior nuclei of the thalamus. The *medial part* lies between the internal medullary lamina on the lateral side and the third ventricle on its medial side and contains the medial nucleus of the thalamus. These two parts are phylogenetically the oldest portion of the thalamus and together comprise the *palaeothalamus*. They have, however, become modified in structure and progressively differentiated in the process of evolution, and it must not be assumed that their functions have remained entirely primitive. The *lateral part* lies between the internal and external medullary laminae. It is the largest of the three parts, forming the greater part of the thalamus and constitutes the *neothalamus*. It reaches its greatest development in anthropoid apes and man. It is subdivided into two groups of nuclei, the dorsolateral part containing the lateral nuclei and the ventromedial part containing the ventral nuclei. The lateral nuclei extend into the pulvinar with which the lateral part is continuous posteriorly. In addition to the above mentioned nuclei, there are a number of smaller nuclear groups in the internal medullary lamina called the *intrathalamic nuclei*.

Connexions (fig. 862).—In man the thalamus is a large cell-station interposed on the sensory path to the cortex and relaying a number of different impulses to the corpus striatum. It receives *afferents* from: (1) the mamillothalamic tract and (2) the hypothalamus (visceral sensibility); (3) the medial lemniscus (proprioceptive and tactile sensibility); (4) the spinal lemniscus (pain and temperature); (5) the trigeminal lemniscus (sensibility from the trigeminal area); (6) the superior cerebellar peduncle of the opposite side; (7) the rubrothalamic tract of the same side; and (8) all parts of the cerebral cortex.

Its *efferents* proceed through the internal capsule to reach all parts of the cerebral cortex, but especially the postcentral gyrus, the parietal association area, the motor, premotor and frontal areas, the gyrus cinguli, the parastriate area and the posterior orbital gyrus of the frontal lobe. In addition, numerous internuncial fibres connect the various parts of the thalamus to one another, and pass between the thalamus and the corpus striatum.

The *anterior part* of the thalamus receives *afferent fibres* through the mamillothalamic tract, which is now regarded as a pathway from the hypothalamus conveying impulses concerned with visceral and other autonomic activities (p. 1048). Its *efferent fibres* pass to the gyrus cinguli (*areas* 23 and 24), (p. 1048).

The *medial part* receives *afferent fibres* from the anterior nucleus, from some of the nuclei of the hypothalamus, through the periventricular system of fibres, and from the frontal area of the cortex (p. 1043). Its *efferent fibres* project on to the frontal area and to the posterior orbital gyrus (p. 1049). Like the anterior part it appears to be concerned largely with autonomic activities.

The *lateral part* of the thalamus, as already stated, consists of a ventral and a lateral group of nuclei.

The caudal part of the *ventral group of nuclei* receives afferent fibres from the spinal, medial and trigeminal lemnisci, which retain the somatotopical arrangement found at lower levels (p. 944), the fibres from the lower limb being situated most laterally, while the fibres from the upper limb are more medial and adjoin the trigeminal fibres from the head. There is considerable overlapping of the fibres of the spinal and medial lemnisci but the fibres of the medial lemniscus tend to extend more rostrally than the fibres of the lateral lemniscus. The most medial part of the ventral nuclei forms a

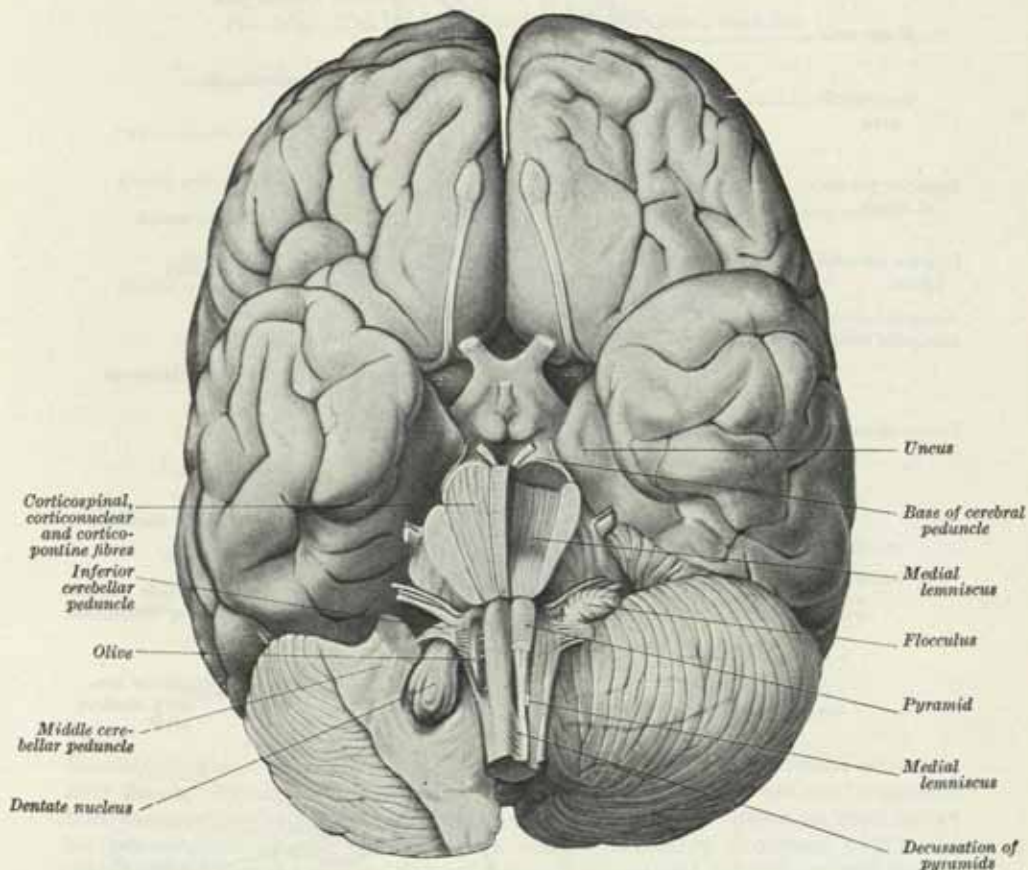
* In the *Nomina Anatomica* these are termed the *anterior*, *medial* and *lateral nuclei*; the term *part* is less confusing and is preferred here.

† Apart from the actual terminology used, the descriptions in the text are largely based on the work of W. E. Le Gros Clark (*J. Anat.*, Lond., 67, 1933, 70, 1936 and 71, 1937, and *Brain*, 55, 1932, and 56, 1933, etc.), and A. Earl Walker, (*The Primate Thalamus*, 1938, University of Chicago Press, *J. Comp. Neurol.*, 62, 1935, *J. neur. ment. Dis.*, 85, 1937, *Res. Publ. Ass. nerv. ment. Dis.*, 23, 1942, etc.); and others.

crescent-shaped group of cells and is often termed the 'arcuate nucleus'; it receives the trigeminal lemniscus. The efferent fibres of the cells around which the medial, spinal and trigeminal lemnisci fibres synapse traverse the posterior limb of the internal capsule and project on to the postcentral gyrus (areas 3, 1 and 2) but some pass to the adjoining motor cortex (see also p. 1040).^{*} Those which run below the lentiform nucleus intervene between it and the anterior perforated substance and constitute a part of a complex bundle termed the ansa peduncularis (see p. 1032).

The rostral part of the ventral nuclei receives afferents from the dentate nucleus of the opposite side of the cerebellum through the superior cerebellar peduncle and from

FIG. 861.—The base of the brain, showing a dissection of the great motor and sensory pathways.



the red nucleus by the rubrothalamic fibres; it sends its efferents to the motor and premotor cortices (areas 4 and 6). There is evidence to show that in this part of the ventral nuclei there is a spatial representation similar to that described above for the fibres of the trigeminal, spinal and medial lemnisci. Other efferents have been ascribed to the substantia nigra and the subthalamic nucleus.

The lateral nucleus has arisen as an upward expansion of the foregoing parts *but it receives no somatic afferent fibres*. Its afferents are derived from the adjoining parts of the thalamus and its efferents project to the parietal association area and probably to other cortical areas (p. 1004).

The *pulvinar* occupies the whole breadth of the posterior fourth of the thalamus and constitutes its most posterior portion. It appears late in phylogenetic history and it expands concurrently with the growth and elaboration of the anterior and middle parts of the inferior parietal lobule (areas 39 and 40), (p. 1047). *It receives no afferent somatic fibres*, but it is intimately associated with the special senses of sight and hearing, for it sends its efferents to the parastriate area† (18), the auditopsychic area (22) and the adjoining parts of the inferior parietal lobule† (p. 1047), and the possibility

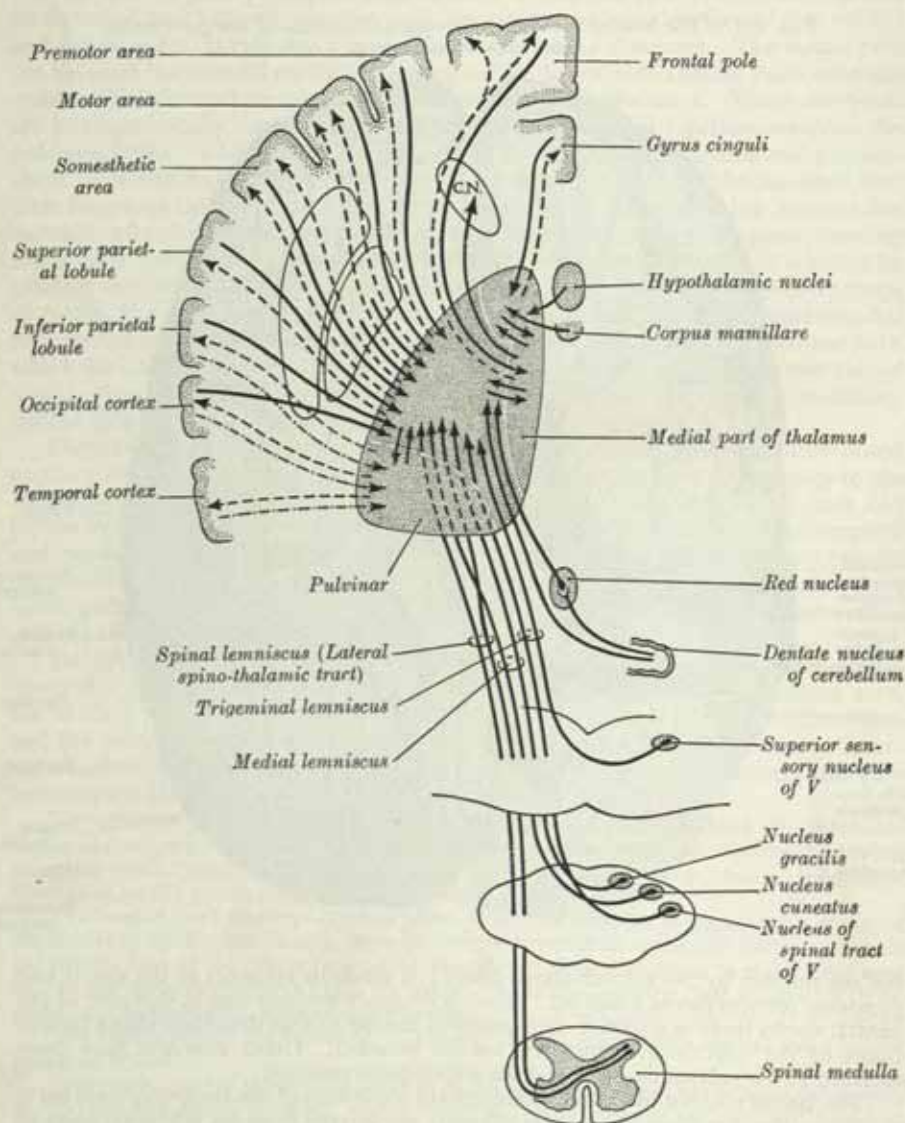
^{*} The spatial relationships between this nucleus and the cortex of the postcentral gyrus is described by W. E. Le Gros Clark and T. P. S. Powell in *Proc. Roy. Soc. B.*, **141**, 1953.

† W. E. Le Gros Clark and D. W. C. Northfield, *Brain*, **60**, 1937.

of a reciprocal flow of afferents from these sources is not excluded. In addition, there is evidence that the medial part of the pulvinar sends efferents to the temporal pole.*

Functional significance of the thalamus and metathalamus (p. 1006).—These parts are to be considered as important subcortical correlation centres. Into them stream impulses from all kinds of somatic receptors, including the eye and the ear, and from splanchnic receptors. One function of the thalamus is to relay and

FIG. 862.—A scheme to show the principal connexions of the thalamus.



Note.—Arrow-heads represent the terminals of fibres.

The thalamo-cortical fibres are shown as interrupted lines for purposes of clarity only, while the fibres of the lemnisci are interrupted where they would otherwise be hidden by the pulvinar. The cortical projections to the pulvinar, which are of doubtful authenticity, are shown by lines which are alternately interrupted and dotted.

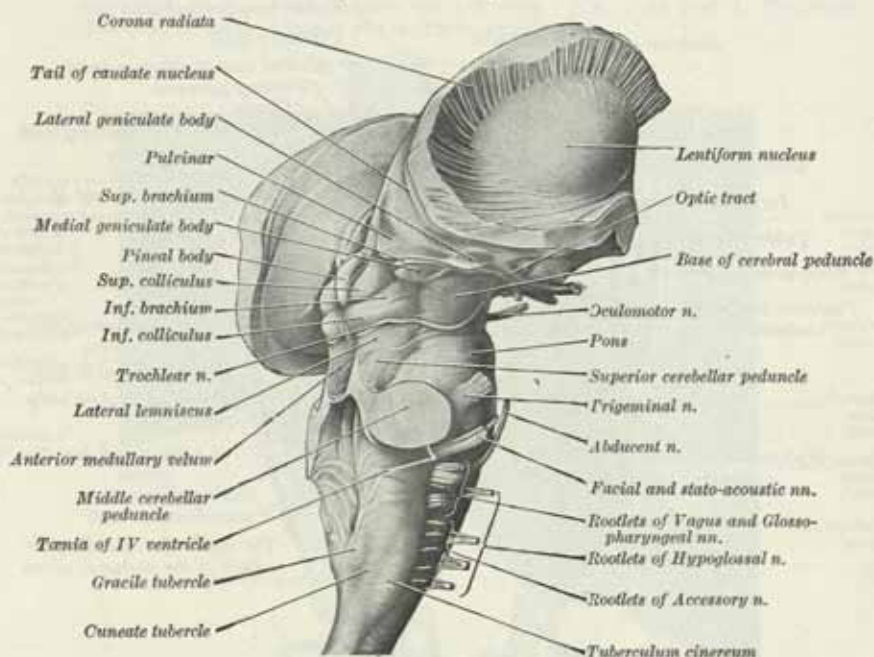
transmit the impulses, possibly with some modification, to the specific reception areas of the cerebral cortex. The thalamus, however, is not only the gateway for sensory impulses entering the cerebral cortex but there is ground for supposing that some, at least, of its activities can be appreciated in consciousness. In the finer appreciation of sensations the cerebral cortex appears to be essential but the cruder

* D. A. Simpson, *J. Anat.*, Lond., 86, 1952.

forms, especially pain, are said to be also consciously experienced after the connexions between the thalamus and cortex have been destroyed.* Partial and total decortications of one cerebral hemisphere have been performed in man in operations for cerebral tumours and after a short interval contralateral painful stimuli can again be experienced, although their localisation is defective but the interpretation of proprioceptive stimuli remains permanently abolished.† These results could, of course, be explained by assuming that the exteroceptive pathways have bilateral representation in the cortex, whereas the proprioceptive pathways are represented unilaterally.

The wealth of thalamo-cortical and cortico-thalamic connexions suggests a close

FIG. 863.—The hind-brain and mid-brain, viewed from the posterolateral aspect.



functional relationship between the two. By these pathways the cortical areas may alter the activity of the thalamic relay centres and vice versa. It has been suggested that the cortico-thalamic connexions enable the cerebral cortex to exercise an inhibitory effect on the spread of the sensory excitatory processes within the thalamus and that the release of the thalamus from cortical control accounts for the exaggerated response to stimuli which characterises certain lesions involving the thalamus. In addition electrical stimulation in man and animals indicates that some of the smaller thalamic nuclei not concerned with specific pathways have a widespread non-specific effect on cerebral activity.‡ Alteration of the rhythm of the brainwaves and changes of consciousness ranging from 'alerting' of the cortex and arousal to apparently normal sleep are described.

As already stated (p. 1002), the medial part of the thalamus receives afferents from the hypothalamus, which contains higher centres associated with the autonomic system and the viscera. The cortical connexions of this part with the frontal area and the posterior orbital gyrus bring visceral activities under the influence of the cortex and so provide a mechanism whereby the cortex is enabled to control or inhibit emotional and instinctive reactions which would otherwise result from visceral stimuli (*see also* p. 1049).

Fishes and, to a less extent, amphibia are dependent on the palæothalamus for

* W. Penfield, *Proc. Roy. Soc., B.*, **134**, 1947.

† W. E. Dandy, *Johns Hopk. Hosp. Bull.*, **53**, 1933.

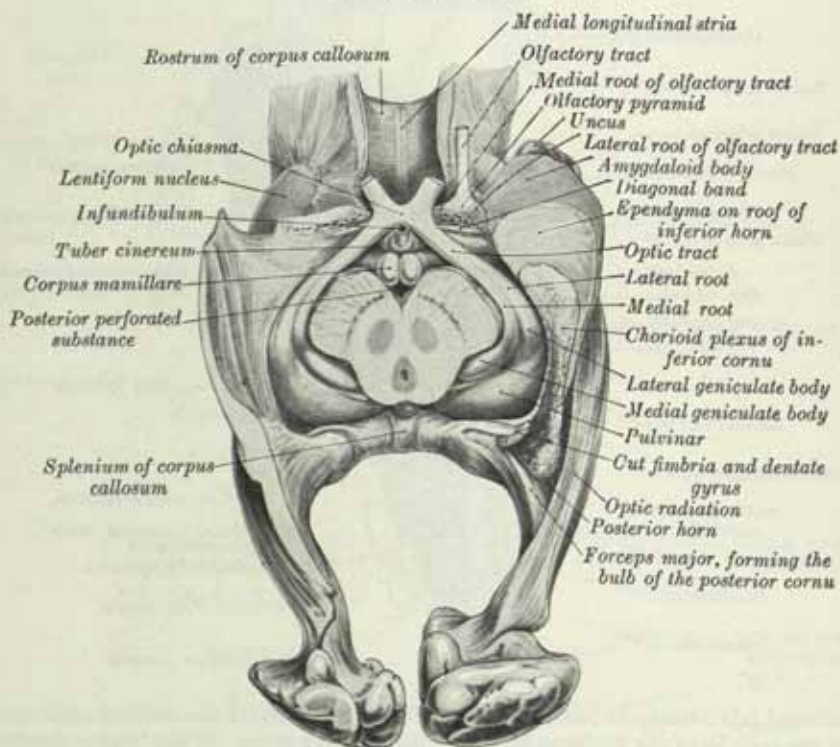
‡ M. Gastant, F. Bremer and W. R. Hess, *Brain Mechanisms and Consciousness*, Oxford, 1954.

the appreciation of harmful or beneficial stimuli. Co-ordinated impulses arise in the thalamus and subthalamic region and result in the avoidance or the quest of such stimuli, as the case may be. In man such stimuli receive recognition in the thalamus, but areas of the cerebral cortex are necessary for their analysis and localisation.

The **metathalamus** (fig. 863) comprises the geniculate bodies, which are two in number—a medial and a lateral—on each side.

The *medial geniculate body* lies under cover of the pulvinar of the thalamus, and lateral to the colliculi. Oval in shape, with its long axis directed forwards and laterally, it is lighter in colour and smaller in size than the lateral geniculate body.

FIG. 864.—A dissection of the brain from below, showing the metathalamus and the optic tracts.



On the right side of the figure the inferior horn of the ventricle is exposed. The floor has been removed but the chorioid plexus is *in situ* and obscures most of the roof.

Through the inferior brachium it receives auditory fibres from the lateral lemniscus and a few from the inferior colliculus of both sides. Its cells send their axons to the cortex of the temporal lobe, *areas* 41 and 42 (fig. 889).

The *lateral geniculate body* (figs. 864, 883) is an oval elevation on the surface of the brain inferior to the lateral part of the posterior end of the thalamus and is connected with the superior colliculus by the superior brachium. It receives a large proportion of the fibres of the optic tract, the remainder—smaller in diameter and, therefore, more slowly conducting—passing through the superior brachium to the superior colliculus and the pretectal nucleus (p. 997) to mediate some of the optic reflexes (p. 1256).

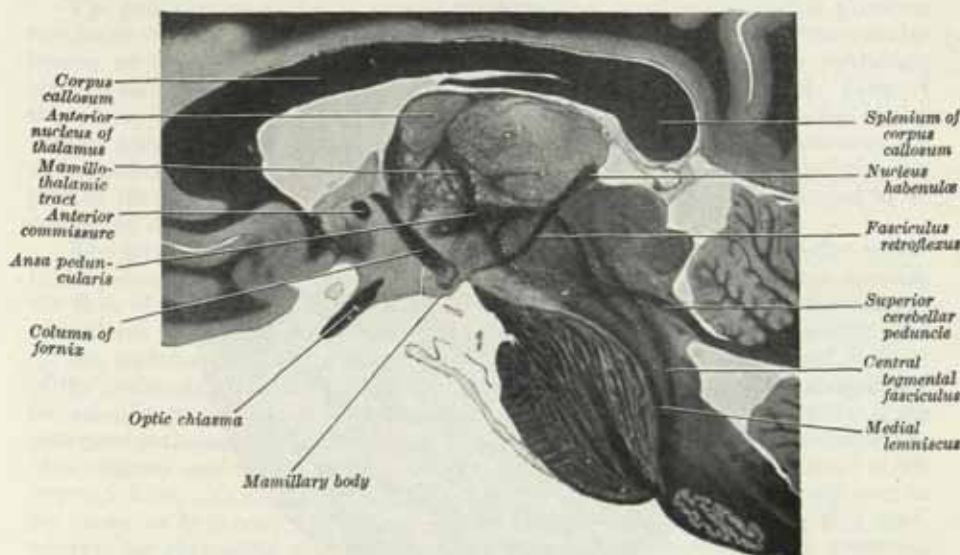
The superior colliculus, the pulvinar and the lateral geniculate body were previously termed the lower visual centres, but it must clearly be understood that the *great majority, if not all, of the fibres which are destined for the visual cortex are relayed in the lateral geniculate body*. Brouwer and Zeeman excised portions of the retina in rabbits, cats and monkeys and were unable to trace any degenerated fibres of the optic tract into the pulvinar. Further, they were able to localise the retinal fibres in definite areas of the lateral geniculate body. Fibres from the upper half of the retina are connected to its medial portion, those from the lower

half of the retina to its lateral portion. Macular fibres end in the central zone, and the area allotted to them is a large one (fig. 872). Those fibres from the nasal side of the retina which are concerned only with monocular vision terminate in the ventral part of the lateral geniculate body (fig. 872), the area concerned being narrow and strip-like.

The cells of the lateral geniculate body are arranged in six layers. Of these, laminae 1, 4 and 6 receive contralateral optic fibres, and laminae 2, 3 and 5, ipsilateral fibres. The cells of laminae 1 and 2 are large and pigmented, while in the other laminae they are smaller and more closely crowded together. Each optic fibre, on reaching its appropriate lamina, divides into five or six terminal branches, each of which ends in a terminal bouton, closely applied to the body of one cell only. A

FIG. 865—A parasagittal section through the brain, cutting the lateral part of the right mamillary body. Viewed from the left side. (Ch. Foix and J. Nicolesco, *Anatomie cerebrale*, Masson et Cie, Paris, 1925.)

Stained to show the white fibres.



Note.—The fasciculus retroflexus is seen crossing the medial side of the red nucleus, which is surrounded by a capsule of white fibres derived chiefly from the superior cerebellar peduncle.

minute lesion of the retina is always associated with transneuronal atrophic changes in a small group of cells similarly disposed in each of the three corresponding laminae,* and it would appear that each unit of the retina projects on to all three laminae, the relationship being, for all practical purposes, of the 'point-to-point' character. This fact has been correlated with the Young-Helmholtz theory of colour vision, and it has been suggested that the three laminae correspond to the three fundamental colour sensations, red, green and violet.† In this connexion, it should be noted that the laminae, though clearly defined in the central part of the nucleus, which is concerned with macular vision, tend to merge with one another in the parts of the nucleus concerned with peripheral vision (fig. 872). Perception of colour is restricted, to a very large extent, if not wholly, to the macular area.

Corresponding cell-groups in the six laminae project on to a very limited area of the visual cortex (fig. 891, area 17), for a minute lesion of the visual cortex is always accompanied by recognisable changes which affect a small group of cells similarly disposed in each layer.‡

* W. E. Le Gros Clark and G. G. Penman, *Proc. Roy. Soc., B*, **114**, 1934.

† W. E. Le Gros Clark, *J. Anat., Lond.*, **75**, 1941, and *Physiol. Rev.*, **22**, 1942. The view that there is also a separate yellow-sensation has recently been reaffirmed and evidence has been adduced in its support by H. Hartridge, *Nature*, **160**, 1947.

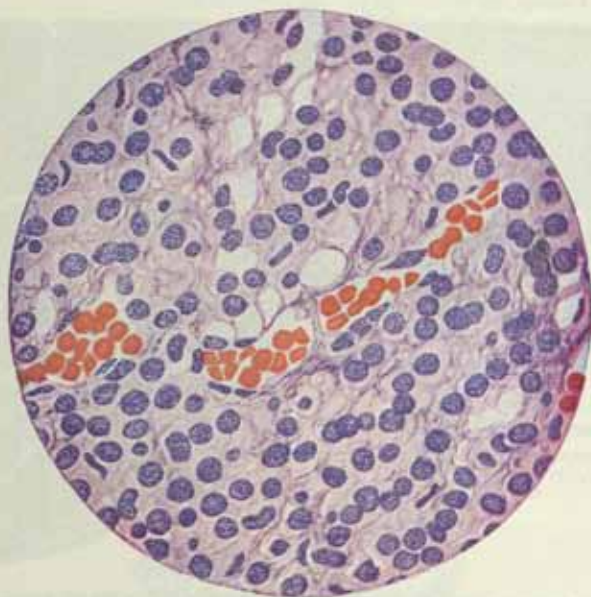
‡ S. Polyak, *J. Comp. Neurol.*, **57**, 1933.

All recent investigations suggest that the lateral geniculate body is purely a relay station. Its afferent fibres are derived solely from the optic tract and its efferent fibres all travel in the optic radiation to the visuo-sensory cortex in the occipital lobe of the brain. In consequence retinal impulses reach the visual cortex without being subjected to any modifying influences.

The **epithalamus** comprises the trigonum habenulæ, the pineal body, and the posterior commissure.

The *trigonum habenulæ* is a small, depressed, triangular area, situated in front of the superior colliculus and medial to the posterior part of the thalamus, from which it is separated by the sulcus habenulæ (fig. 859). It contains a group of nerve-cells named the *habenular nucleus* (fig. 865). Afferent fibres are conveyed to the nucleus by the *stria medullaris thalami* (*stria habenularis*), which is formed at the anterior end of the thalamus by fibres which ascend from the anterior perforated substance and by

FIG. 866.—A section through the pineal body of a young adult. Stained with hæmatoxylin and eosin. $\times 350$. (Drawn from a preparation kindly lent to the Editors by Dr. E. E. Hewer.)



fibres from the column of the fornix (fig. 884). The stria then passes backwards on the uppermost part of the medial surface of the thalamus (p. 1001) and forms the medial boundary of the trigonum habenulæ. Some of the fibres cross in the peduncle of the pineal body and reach the habenular nucleus of the opposite side. They constitute the *habenular commissure*. Efferent fibres leave the nucleus and pass ventrally forming the *fasciculus retroflexus* (fig. 865). They descend medial to the red nucleus and end in the interpeduncular nucleus (p. 1010); some are described as reaching the substantia nigra of the mid-brain. The habenular nucleus and its afferent and efferent paths constitute a portion of the rhinencephalon.

The *pineal body* * (figs. 859, 870) is a small, conical, reddish-grey body which lies in the depression between the superior colliculi. It is placed below the splenium of the corpus callosum, but is separated from it by the tela chorioidea of the third ventricle and the contained cerebral veins. It is enveloped by the lower layer of the tela, which is then reflected over the tectum (fig. 870). The pineal body measures about 8 mm. in length, and its base, directed forwards, is attached by a stalk or peduncle of white substance. The stalk divides anteriorly into two laminae, a superior and an inferior, which are separated from each other by the pineal recess of the third ventricle (fig. 870). The inferior lamina contains the posterior commissure and the superior lamina the habenular commissure.

Structure (fig. 866).—The bulk of the parenchyma of the pineal gland consists of

* See R. J. Gladstone, and C. P. G. Wakeley, *The Pineal Organ*, London, 1940.

rounded cells, the so-called *pineal cells*, with irregular nuclei poor in chromatin. At birth a few neuroglia-cells and nerve-cells are present. Connective tissue cells and fibrils appear during the first year, and gradually increase in quantity; the rate at which fibrosis takes place is very variable. Calcareous concretions are constantly present in the pineal body after the seventeenth year; spaces or cysts may also be present.

The human pineal body is developed from the epiphysis, which grows out from the caudal end of the roof-plate of the diencephalon. In cyclostome fishes the epiphysis gives rise to two diverticula, a parietal or parapineal and a pineal organ. Both these derivatives grow towards the dorsal surface of the head, and they become connected to the habenular region by a solid stalk containing nerve-fibres. Their vesicular extremities show a distinct resemblance to the optic vesicle. In sphenodon, one of the most primitive reptiles, the parietal organ reaches the dorsal surface of the head and constitutes the parietal eye, possessing a well-differentiated cornea, lens and retina. The pineal organ, on the other hand, remains as a hollow, glandular structure which pours its secretion into the third ventricle. In mammals the parietal organ disappears at an early stage of embryonic life, and the pineal body is homologous with the pineal organ.

The *posterior commissure* is a small band of fibres crossing the median plane on the dorsal surface of the upper end of the cerebral aqueduct, covered by the inferior lamina of the peduncle of the pineal body. Its fibres acquire their medullary sheaths early, but their connexions have not been definitely determined. Most of them have their origin in the *nucleus of Darkschewitsch* (p. 992), which lies in the ventral grey matter of the upper end of the cerebral aqueduct, dorsolateral to the upper end of the oculomotor nucleus; some are probably derived from the posterior part of the thalamus and from the superior colliculus; others are believed to be continued downwards into the medial longitudinal bundle.

The **hypothalamus** (fig. 870).—Anatomically, the structures included under this heading are (1) the subthalamic tegmental region; (2) the structures forming the floor of the third ventricle, viz. the posterior perforated substance, the corpora mamillaria, tuber cinereum, infundibulum, hypophysis and optic chiasma; and (3) the anterior part of the lateral wall of the third ventricle, below and in front of the thalamus. *Confusion will be avoided if it is observed that the physiologist and the neurologist use the term 'hypothalamus' in a more restricted sense and limit it to the structures contained in the anterior part of the floor of the third ventricle—excluding the optic chiasma and the hypophysis—and to those contained in the lateral wall of the ventricle below and in front of the hypothalamic sulcus. It will become apparent to the reader as he proceeds that the anatomist uses the term in its topographical sense, whereas the physiologist and the neurologist limit it to a functional entity, concerned mainly with visceral control.*

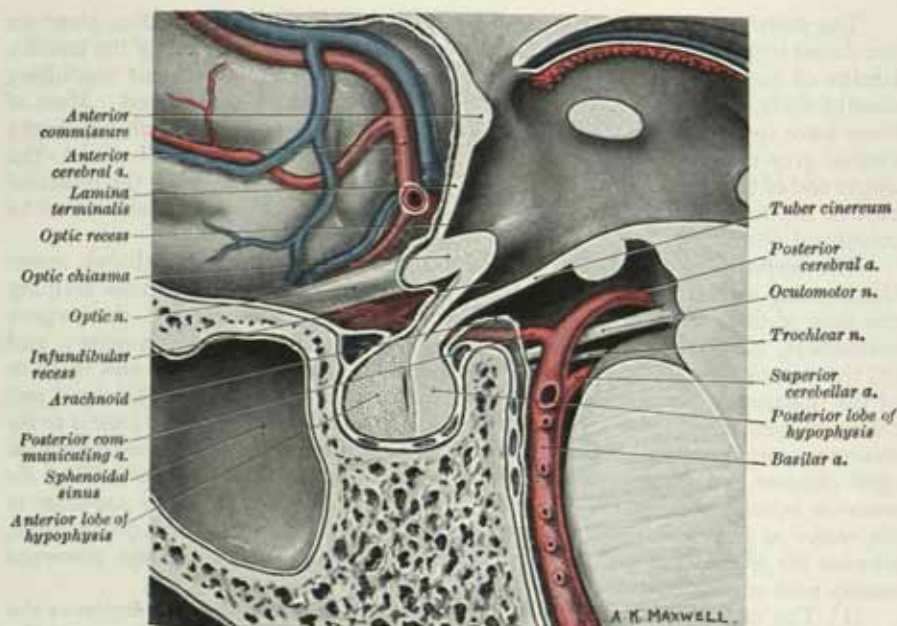
(1) The *subthalamic tegmental region* consists of the upward continuation of the tegmentum beneath the posterior part of the thalamus. The red nucleus and the substantia nigra can be followed into its posterior part, where they gradually diminish, and disappear behind the corpus mamillare. The fibres of the medial lemniscus, on their way to enter the inferior surface of the thalamus, lie first lateral and then dorsal to the red nucleus. Some of the ascending branches of the fibres of the superior cerebellar peduncle pass directly into the thalamus but others end in the red nucleus.

A small, brownish-coloured nucleus, named the *subthalamic nucleus* lies below the lateral part of the thalamus. Shaped like a biconvex lens when seen in coronal sections of the brain, the nucleus lies dorsolateral to the upper end of the substantia nigra and extends backwards as far as the lateral aspect of the red nucleus. Dorsally (or above) it is related to the lateral part of the thalamus, from which it is separated by a narrow area, termed the *zona incerta* (fig. 860). The fibre connexions of the subthalamic nucleus are still obscure, but it is known to receive a substantial bundle of fibres from the *ansa lenticularis*. These fibres arise from the globus pallidus of the lentiform nucleus and enter the dorsal aspect of the subthalamic nucleus, after intersecting the fibres of the internal capsule. In addition it receives afferents from some of the nuclei of the hypothalamus and from the substantia nigra. Its efferent fibres pass to the globus pallidus, the red nucleus and the rostral part of the ventral nucleus of the thalamus. It also sends a group of fibres downwards to the reticular formation of the brain stem (fig. 915). Clinical evidence indicates that destruction of the subthalamic nucleus is associated with uncontroll-

able torsional movements, choreic in type, and exceedingly violent in character, and electrical stimulation* results in contraction of the erector spinae and the deep muscles of the back on the opposite side. The subthalamic nucleus is an important constituent of the extrapyramidal system (p. 1076).

(2) *The structures forming the floor of the third ventricle.*—The *posterior perforated substance* is a small area of greyish substance which lies on the basal surface of the brain in the interval between the diverging cerebral peduncles. It is pierced by a number of small apertures which transmit the posteromedial central branches of the posterior cerebral arteries. In its posterior part it contains a small nucleus, named the *interpeduncular nucleus*, in which the fasciculus retroflexus from the habenular nucleus ends (p. 1008). Little is known concerning the efferent fibres from the nucleus but it has been suggested that they descend into the brain-stem and act as a pathway for unspecified olfactory reflexes.

FIG. 867.—A sagittal section through the hypophysis, *in situ*.
Semi-diagrammatic.



The *corpora mamillaria* (fig. 824) are two round white masses, each about the size of a small pea, placed side by side below the grey matter of the floor of the third ventricle in front of the posterior perforated substance. Each consists of white matter externally and of grey matter internally, the cells of the latter forming two nuclei, a *medial* of small and a *lateral* of large cells. The white matter is mainly formed by the fibres of the columns of the fornix, which descend to the base of the brain and end partly in the corpora mamillaria. From the cells of the medial nucleus a bundle of fibres arises and divides into a *mamillothalamic tract*, which passes upwards into the anterior nucleus of the thalamus, and a *mamillo tegmental tract*, which is directed downwards into the tegmentum. The fibres of the latter may arise as collaterals of the fibres of the mamillothalamic tract or they may arise independently. *Afferent* fibres run forwards to the lateral nucleus from the tegmentum and constitute the *peduncle* of the mamillary body. These are regarded as visceral afferents from the sensory nuclei of the vagus and glossopharyngeal nerves and probably from lower levels of the spinal medulla also, and their relation to the hypothalamus has been compared to the relation of the lemnisci to the thalamus.†

The assessment of the functional significance of the corpora mamillaria must depend on the interpretation accepted for the functional significance of the hippo-

* F. A. Mettler *et al.*, *Arch. Neurol. Psychiat.*, Chicago, 41, 1939.

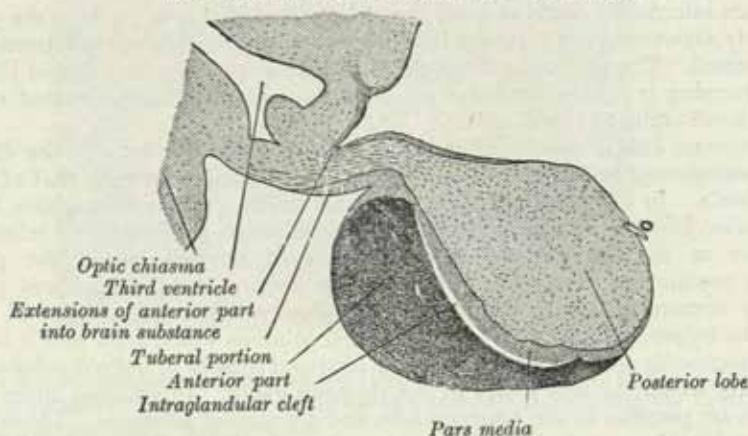
† W. E. Le Gros Clark, in *The Hypothalamus*, Edinburgh, 1938.

campus and the fornix (p. 1034). Until recently regarded—largely on morphological grounds—as essential parts of the rhinencephalon and therefore concerned primarily with the sense of smell, they are now believed to be concerned with general visceral sensibility, possibly influenced to some extent by olfactory impressions. Experimental work involving the destruction of the anterior nucleus of the thalamus* has failed to confirm the association of the corpora mamillaria and the anterior thalamic nuclei with the sense of smell, and there is now a growing tendency to look on the former as the source of one of the main outflows from the hypothalamus to the thalamus and thence to the cortex (gyrus cinguli, p. 1048).

The *tuber cinereum* is a sheet of grey matter which is situated between the corpora mamillaria behind and the optic chiasma in front. From its under surface, which is covered by the tuberal part of the hypophysis (*vide infra*), a hollow conical process, termed the infundibulum, projects downwards and is continuous with the posterior lobe of the hypophysis. On each side the tuber cinereum is continuous with the anterior perforated substance, but is separated from it on the basal surface of the brain by the optic tract. The part of the tuber cinereum which is related to the pars tuberalis of the hypophysis (see below) is frequently termed the *median eminence*.

The region occupied by the tuber cinereum is much more elaborate in fishes and it owes its importance to its intimate topographical relationship to the mouth and

FIG. 868.—A median sagittal section through the hypophysis cerebri of an adult monkey. Semi-diagrammatic. (Herring.)



its consequent association with the sense of taste (Tilney). The dominance of the gustatory by the olfactory sense in air-breathing vertebrates is accompanied by a reduction in the development of this part of the hypothalamus, although several nuclei and commissural pathways have been described. It is in this region that the nervus terminalis (p. 1093) is attached, and the fact that it contains sympathetic fibres is not surprising in the light of recent work on the hypothalamus (p. 1009).

The **hypophysis** (fig. 867), is a reddish-grey, somewhat ovoid body, measuring about 12 mm. in its transverse, and 8 mm. in its anteroposterior diameter. It is continuous with the end of the infundibulum, and is situated in the hypophyseal fossa of the sphenoid bone, where it is roofed in by a circular fold of dura mater, termed the *diaphragma sellae*; this fold is pierced by a small central aperture through which the infundibulum passes, and it separates the anterior part of the upper surface of the hypophysis from the optic chiasma (fig. 867). On each side, the hypophysis is related to the cavernous sinus and the structures which it contains (p. 850). Inferiorly, it is separated from the floor of the fossa by a large, partially loculated, venous sinus,† which communicates freely with the circular sinus. The meninges blend with the capsule of the hypophysis and cannot be identified as separate layers in the fossa.

The infundibulum, which is directed downwards and forwards, contains a

* K. S. Lashley and R. W. Sperry, *Am. J. Physiol.*, **139**, 1943.

† J. Brander, *J. Anat. Lond.*, **66**, 1932.

funnel-shaped recess from the cavity of the third ventricle, and is surrounded (fig. 868) by an upward extension from the anterior lobe of the gland.

The hypophysis consists of an anterior lobe or *adenohypophysis* and a posterior or *neural* lobe, which differ in their development and structure (fig. 869). The *anterior lobe* is the larger, and is somewhat kidney-shaped, the concavity being directed backwards and embracing the posterior lobe. It is developed from a diverticulum of the ectoderm covering the roof of the primitive buccal cavity or stomodeum (p. 185). The cavity of the diverticulum is represented by a narrow cleft or more frequently in the adult by a row of colloid containing vesicles. The portion behind the cleft and immediately adjacent to the posterior lobe is termed the *pars intermedia*, whilst an upward prolongation which surrounds the infundibulum and covers the tuber cinereum is the *pars tuberalis*; the remainder of the anterior lobe is frequently referred to as the *pars distalis*.

The anterior lobe is very vascular and consists of epithelial cells of varying size and shape arranged in cord-like trabeculae, irregular masses or alveoli separated by thin-walled sinusoidal vessels and reticular tissue. The cells are of two main varieties, the *chromophile* and *chromophobe* which are irregularly distributed through the lobe. The chromophile cells can be further subdivided, according to the staining properties of the granules in their cytoplasm, into the alpha cells with eosinophilic granules and the beta cells with basophilic and generally fewer granules. The chromophobe cells are generally slightly smaller and either devoid of granules or containing pale staining granules in their cytoplasm; they are usually readily distinguishable from the chromophile cells.

The *pars intermedia* contains small agranular cells with 'beta' cells in the part immediately adjacent to the posterior lobe; between these cells are small masses of colloid material. The *pars tuberalis* is characterised by the large number of blood vessels traversing it; between these are cords or balls of undifferentiated cells and some small alpha and beta cells.

The *posterior lobe* is developed as a downgrowth from the floor of the diencephalon and during early foetal life contains a cavity continuous with that of the third ventricle. In some animals (e.g., cat) this cavity persists throughout life. The posterior lobe, infundibulum and median eminence are frequently referred to together as the *neurohypophysis*. Although of nervous origin the posterior lobe contains no nerve cells but consists of neuroglial cells and fibres, permeated by numerous fine, mainly unmyelinated nerve fibres from some of the nuclei of the hypothalamus. It is invaded by cell columns which grow into it from the *pars intermedia* and embedded in it are scattered masses of colloid substance histologically similar to that found in the thyreoid gland. In addition there are cells which are peculiar to the posterior lobe and are termed *pituicytes*. These are variable in size, shape and other characters and many of them are provided with long branching processes or fibres which extend some distance from the cell bodies.

The hypophysis receives its blood supply from the internal carotid artery through a superior and an inferior hypophyseal artery on each side. The superior hypophyseal artery supplies branches to the upper part of the infundibulum and hypothalamus. The inferior hypophyseal arteries supply branches to the lower part of the infundibulum and the posterior lobe; these communicate with the branches of the superior hypophyseal arteries.* The arterial branches to the median eminence and infundibulum end in intricate tufts of capillaries from each of which the blood is drained by one or more efferent vessels which descend, mainly through the *pars tuberalis* to break up again to form the sinusoids in the *pars distalis*. These vessels therefore form a hypophyseal portal system and constitute the only afferent channels to the *pars distalis*.† The venous drainage of the hypophysis is by short vessels which emerge over the surface of the gland and enter the neighbouring dural venous sinuses.

Both the anterior and the posterior lobes of the hypophysis produce a number of hormones. It would be out of place, in a textbook such as this, to attempt to give a detailed description of their various actions: it will be sufficient to state that one of the hormones secreted by the anterior part, probably by the alpha

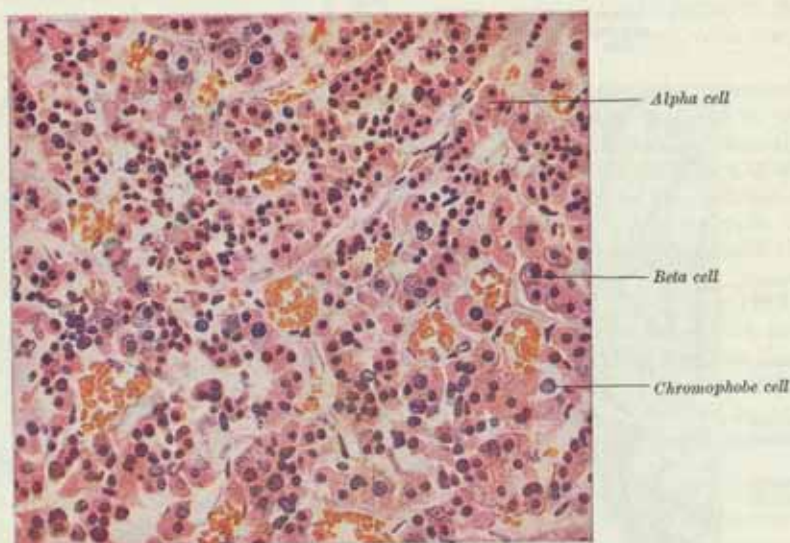
* G. P. Xuereb, M. M. L. Prichard and P. M. Daniel, *Quart. J. Exper. Physiol.*, **39**, 1954.

† G. T. Popa and U. Fielding, *J. Anat. Lond.*, **65**, 1930, and *Lancet*, **2**, 1930; J. D. Green and G. W. Harris, *J. Physiol.*, **108**, 1949, and G. P. Xuereb, M. M. L. Prichard and P. M. Daniel, *loc. cit.*

cells, influences growth, especially of the skeleton; others control the development and activity of the genital, mammary, thyroid and suprarenal glands. The posterior lobe produces hormones which raise the blood-pressure, regulate the outflow of water from the kidney (p. 1015), stimulate contraction of the uterine musculature and raise the blood-sugar.

Applied Anatomy.—New growths of the hypophysis lead to its enlargement and to increase in size of the sella turcica. Adenoma of the 'alpha' cells causes the rare disease of *acromegaly*, which is characterised by gradual increase in the size of the face, hands, and feet, with headache and often a peculiar type of blindness. This blindness is due to the pressure of the enlarging hypophysis on the inferior aspect of the optic chiasma (fig. 867). The pressure causes atrophy of the nerve-fibres coming

FIG. 869.—A section of the anterior lobe of a human hypophysis (from a section lent by Dr. R. S. Snell). Stained with haematoxylin and eosin. $\times 310$.



from the lower nasal quadrants of the retinae, with the result that the patient loses the upper temporal quadrants of his fields of vision while retaining his nasal fields (bi-temporal quadrant hemianopia).

The *optic chiasma* is described on p. 1015.

(3) The *anterior part of the lateral wall of the third ventricle* is separated from the thalamus above and behind by the hypothalamic sulcus; in front it adjoins the lamina terminalis which, although strictly a part of the telencephalon, is included in the hypothalamus; laterally it abuts on the subthalamie tegmental region and below are the optic chiasma and tracts and the structures in the interpeduncular fossa.

It will be remembered that those parts of the wall of the neural tube which are most intimately related to the sulcus limitans in the spinal medulla and brain stem give rise to those groups of nerve-cells which are associated with visceral activities. The position of the hypothalamic sulcus in the diencephalon strongly suggests its identification with the sulcus limitans; if this identification is accepted, it will not be surprising to find that in its immediate neighbourhood there develop a number of nuclei which are all intimately concerned with the viscera and vasomotor apparatus. Further, the relationship between some of these nuclei and the hypophysis is very intimate and the whole hypothalamus is now generally regarded as a complex neuroglandular mechanism which is concerned with the regulation and co-ordination of visceral and vasomotor activities.

Some of the nuclei in this region and their connexions are more clearly defined than others.* Covering the upper surface of the optic chiasma and the commence-

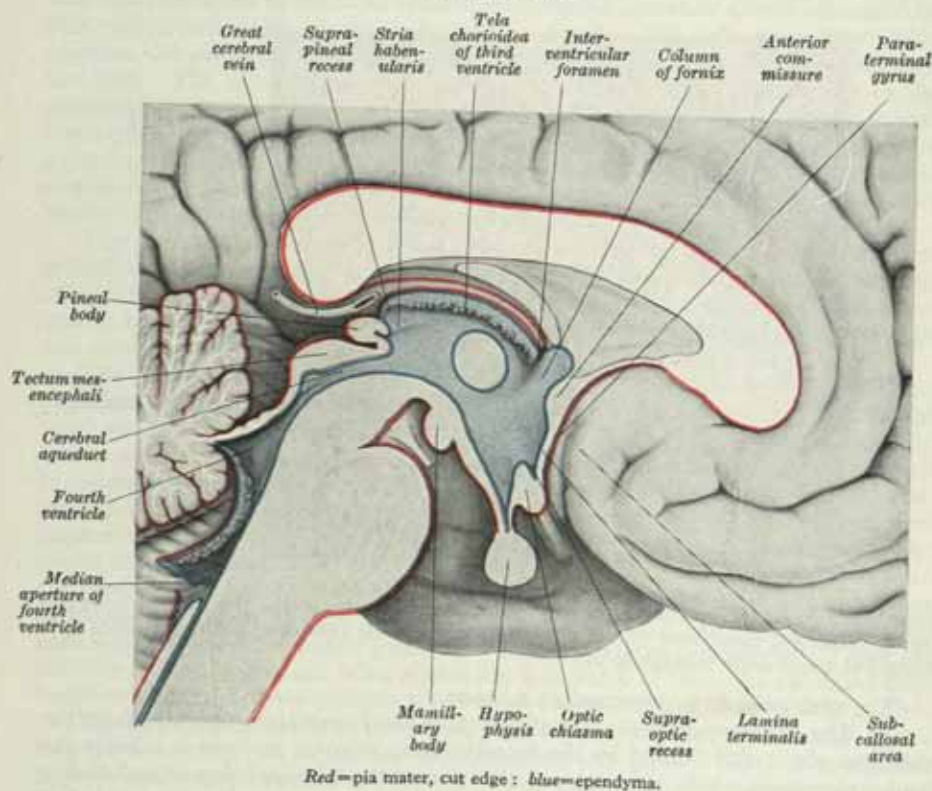
* For details see S. W. Ranson, *Bull. of the New York Acad. of Med.*, 1937, W. E. Le Gros Clark and others, *The Hypothalamus*, Edinburgh, 1956, and W. R. Ingram, *Res. Publ. Ass. Nerv. Ment. Dis.*, 20, 1940.

ment of the optic tract is the *supraoptic nucleus*; above and incompletely separated from it is the *paraventricular nucleus*. These two nuclei are composed of large nerve-cells and are characteristically very vascular. In lower vertebrates they are represented by a single nucleus termed the *preoptic nucleus*.

Above the tuber cinereum and close to the ependyma of the third ventricle is the *ventromedial nucleus* and, above it, the *dorsomedial nucleus* of the hypothalamus. These two nuclei are not very clearly defined in the adult human brain. Lateral to the ventromedial nucleus are small groups of cells which constitute the *tuberal nuclei*.

Above the mamillary body and caudal to the ventromedial and dorsolateral nuclei is an ill-defined group of cells which constitutes the *posterior nucleus* of the

FIG. 870.—Part of a median sagittal section through the brain. Compare with fig. 873.



hypothalamus. In front of and lateral to this are scattered cells which constitute the *lateral nucleus* of the hypothalamus.

Intervening between the lateral and tuberal nuclei on the lateral side and the ventromedial, dorsomedial and posterior nuclei on the medial side are the fibres of the columns of the fornix, the mamillothalamic tract and the fasciculus retroflexus. Between the most medially placed nuclei and the ependyma of the third ventricle is a system of fine nerve-fibres termed the *periventricular fibres*.

Afferent nerve-fibres reach the hypothalamic nuclei from the tegmentum of the midbrain, anterior olfactory areas, hippocampus, mamillary bodies, thalamus, lentiform nucleus and cerebral cortex. The afferent fibres from the midbrain are carried in the peduncle of the mamillary body. These are believed to carry splanchnic afferent impulses from nuclei in the brain stem and from the spinal medulla. The fibres from the anterior olfactory areas are conveyed in the *medial forebrain bundle* which passes backwards to the brain stem through the lateral regions of the hypothalamus, lateral to the fornix and mamillothalamic tract and amongst the cells of the lateral nucleus of the hypothalamus. The fibres from the cerebrum come from the cortex of the frontal lobe, many of them reach the hypothalamus

direct but a few are believed to relay in the medial nucleus of the thalamus and reach the hypothalamus through the periventricular system.

Efferent fibres from the supraoptic, paraventricular and tuberal nuclei pass through the tuber cinereum and the stalk of the hypophysis to terminate mainly in the posterior lobe of the hypophysis. Some may project into the pars tuberalis and pars intermedia. The nature and precise location of the nerve terminals in the posterior lobe of the hypophysis is in doubt but it has been suggested that many terminate close to or on the walls of the blood vessels. Efferent fibres also pass to the medial nucleus of the thalamus in the periventricular system and to the anterior nucleus in the mamillothalamic tract. There are several efferent pathways to the brain stem—through the posterior part of the periventricular system, through the diffuse system of fibres which permeates the hypothalamus and is continued caudally to the midbrain and along the mamilloreticular tract and the medial forebrain bundle.* The descending fibres from the posterior part of the periventricular system pass ventral to the posterior commissure, cerebral aqueduct and fourth ventricle as the dorsal longitudinal fasciculus (of Shütz). Impulses to the brain-stem pass to the reticular formation and are believed to descend, with many relays, to the spinal medulla.

The hypothalamic region contains important centres controlling the autonomic nervous system. The parasympathetic centre is believed to be situated in the anterior and tuberal parts whilst the sympathetic centre is situated posteriorly. These centres are believed to be under the inhibitory influence of the cortex of the frontal lobe particularly in the regions which lie above and around the rostrum of the corpus callosum. When this inhibitory influence is abolished in animals, by destruction of this area of cortex, a condition of 'sham rage' results in which the animal readily exhibits outbursts of rage.†

The supraoptic, tuberal and possibly the paraventricular nuclei are closely associated with the function of secretion of the antidiuretic hormone by the posterior lobe of the pituitary. The precise nature of the interrelation between these parts is not clear but it has been recently suggested that these nuclei in the hypothalamus are sensitive to small changes in osmotic pressure and may act as very sensitive osmometers. Destruction of the supraoptic-hypophyseal nerve pathway results in the condition of diabetes insipidus.‡

Clinical observations and experimental lesions in the hypothalamus show that this region is also closely connected with the control of fat and carbohydrate metabolism, heat regulation, sexual activities, and sleep. Clinical lesions, tumours or encephalitis lethargica of this region may therefore result in adiposity, hyperglycaemia, hyper- or hypothermia, sexual disturbance and disturbance of the sleep rhythm. The precise localisation of the controlling centres in each case is not known and these disturbances cannot as yet be associated with specific nuclei.

Optic chiasma.—The optic chiasma (fig. 864) is a flattened, somewhat quadrilateral, bundle of nerve-fibres situated at the junction of the anterior wall of the third ventricle with its floor. Its anterolateral angles are continuous with the optic nerves, and its posterolateral angles with the optic tracts. The lamina terminalis (p. 1019) is attached to its upper surface and is crossed, just above the chiasma, by the anterior communicating artery. Inferiorly the chiasma rests on the diaphragma sellae just behind the optic groove of the sphenoid bone, and is thus in close relation to the hypophysis (fig. 867). Posteriorly it is related to the tuber cinereum and the infundibulum below, and to the third ventricle above. Laterally it is related to the termination of the internal carotid artery and the anterior perforated substance. A small recess of the third ventricle, named the optic recess, passes downwards and forwards over its upper surface as far as the lamina terminalis (fig. 867).

Most of the fibres of the optic chiasma take origin in the retina and reach the chiasma through the optic nerves. In the chiasma the fibres from the nasal half of each retina, including the nasal half of the macula, cross the median plane and enter the optic tract of the opposite side, while the fibres from the temporal half do not cross but pass backwards in the optic tract of the same side. The macular fibres from both eyes form a bundle, flattened from above downwards, which occupies the

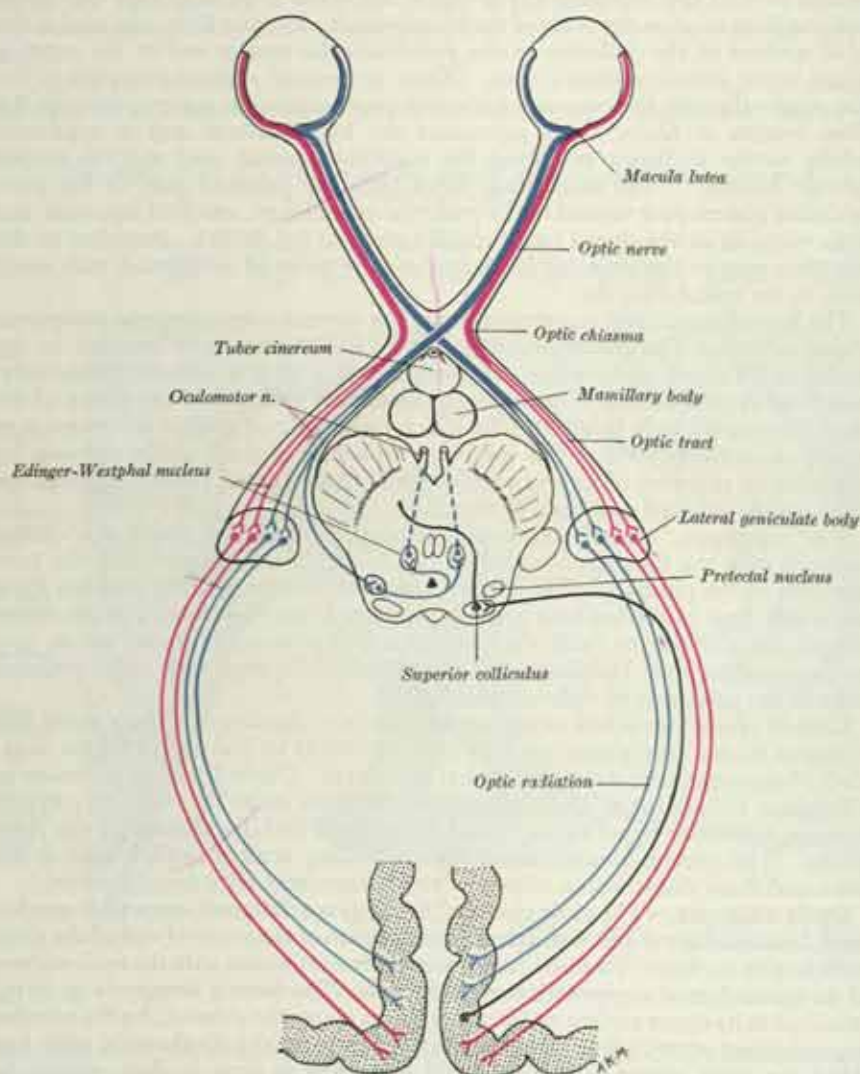
* S. W. Ranson and H. W. Magoun, *Ergebn. Physiol.*, **41**, 1939.

† P. Bard and V. B. M. Mountcastle. *Res. Publ. Ass. Nerv. Ment. Dis.*, **27**, 1948.

‡ For details and full list of references see G. W. Harris, *Neural Control of the Pituitary Gland*, London, 1955.

central part of the chiasma and separates the lower nasal quadrant fibres—which lie in the lower part of the chiasma—from the upper nasal quadrant fibres—which lie in the upper part of the chiasma. Dorsal to and within the optic chiasma are

FIG. 871.—A scheme showing some of the connexions of the optic nerves and optic tracts, and the path of the light reflex.



bundles of fibres which are not derived from the optic nerve and form no part of the visual pathway. Although these are termed, collectively, the supraoptic commissures, they are not really commissures but decussations. One of these is the *commissure of Gudden*, which was formerly, but incorrectly, believed to connect the medial geniculate bodies of the two sides. Its connexions are not fully known but evidence, from work on animals, suggests that its fibres arise in the brain-stem and spinal medulla;* its existence, in man, is denied by some authorities.†

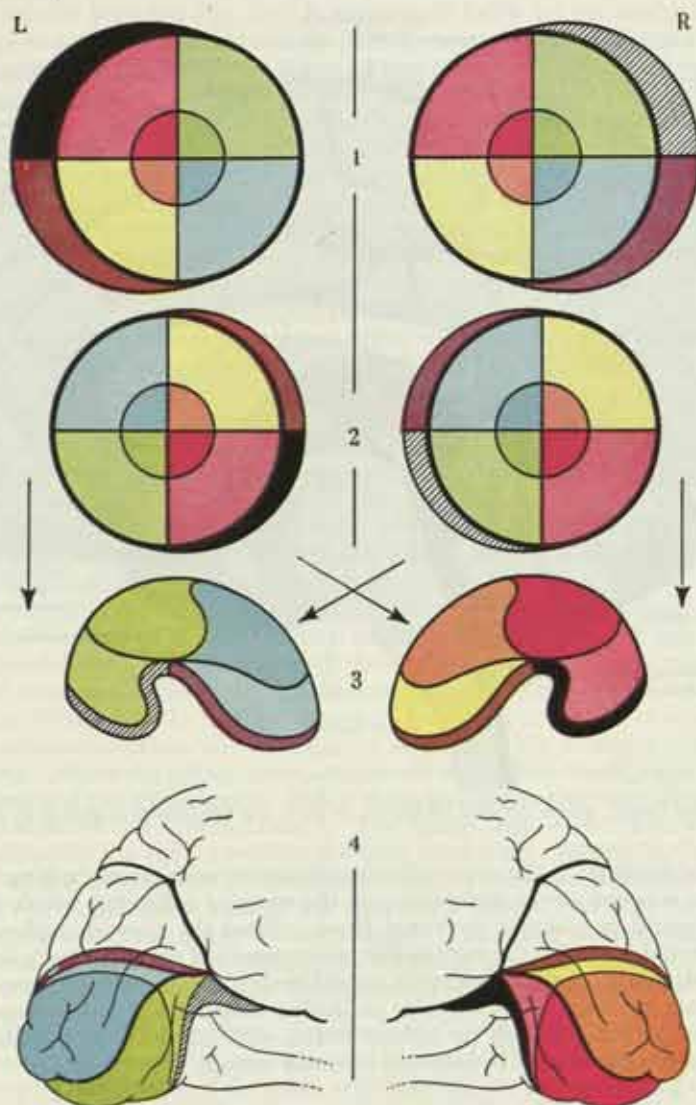
Optic tracts.—The optic tracts (figs. 864, 871 and 875) are continued backwards and laterally from the posterolateral angles of the chiasma. Each passes between the anterior perforated substance and the tuber cinereum, forming the anterolateral boundary of the interpeduncular fossa. The tract becomes flattened and winds

* P. Glees, *J. Anat. Lond.*, 78, 1944, and Hsiang-Tung Chang and T. C. Ruch, *J. Anat. Lond.*, 83, 1949.

† O. Larsell, *Anatomy of the Nervous System*, 2nd Edition, New York, 1951.

round the upper part of the cerebral peduncle, to which it adheres closely. In this part of its course it is hidden from view on the basal surface of the brain by the uncus and the parahippocampal gyrus. Reaching the lateral geniculate body it divides into a medial and a lateral root. The medial root comprises the fibres of Gudden's com-

FIG. 872.—A diagram to show the projection of the visual fields (1) on the retinae (2), the lateral geniculate bodies (3), and the striate areas of the occipital cortex (4). (Modified from S. Polyak, *Publications in Anatomy*, Univ. of California Press.)

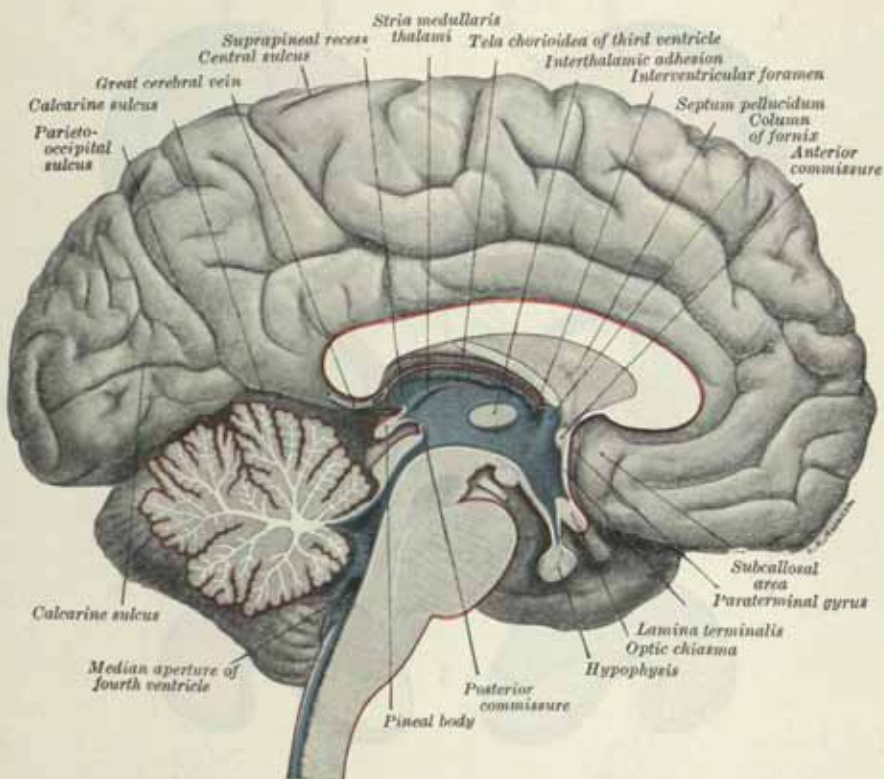


Darker shades are used for the macular areas and lighter shades for the corresponding quadrants of the peripheral retina. The peripheral strips on the nasal side of each retina (2) are coloured differently on the two sides: they are associated with monocular vision only. The corresponding cortical areas for monocular vision are shown for the human brain, but may be regarded as somewhat speculative. The arrows indicate the paths of the fibres in the optic chiasma. Note that the fibres from peripheral parts of the retina project to the whole width of the cell laminae in the rostral third of the geniculate body, but cannot be shown here.

missure. The lateral root consists mainly of afferent fibres which arise in the retina and undergo partial decussation in the optic chiasma, as already described, but it also contains a few fine efferent fibres which are passing forwards to terminate in the retina. Most of the fibres of the lateral root are found to end in the lateral geniculate body (p. 1006), but some sweep medially below the pulvinar and gain the superior colliculus and the pretectal nucleus (p. 997). New fibres arise from the nerve-cells

in the lateral geniculate body, and pass through the posterior limb of the internal capsule. Emerging from the capsule as a broad bundle termed the *optic radiation*, the fibres of the second visual neurones curve backwards and medially to reach the cortex of the occipital lobe of the cerebrum, where the higher or cortical visual centres are situated (p. 1045). On their way they are separated from the posterior cornu of the lateral ventricle only by the tapetum of the corpus callosum.

FIG. 873.—A median sagittal section through the brain.



The pia mater, where divided, is shown in red; the ependyma is shown in blue.

Some of the fibres in the optic radiation take an opposite course, arising from the cells of the occipital cortex and passing to the superior colliculus, which therefore receives cortical in addition to retinal fibres. From the superior colliculus new fibres arise and travel by the tectobulbar and tectospinal tracts to reach the nuclei of the third, fourth, sixth and eleventh cranial nerves, and the anterior grey column of the spinal medulla. The superior colliculus constitutes a lower visual centre which is concerned, through its cortical fibres, with the reflex movements of the head and eyes which occur in response to visual stimuli.

THE THIRD VENTRICLE

The **third ventricle** (figs. 859, 870, 873), which is the derivative of the vesicle of the primitive fore-brain, is a median cleft between the two thalami. Behind, it communicates with the fourth ventricle through the cerebral aqueduct, and in front with the lateral ventricles through the interventricular foramina. It has a roof, a floor, an anterior and a posterior boundary, and two lateral walls.

The *roof* (fig. 870) is formed by a layer of ependyma which stretches between the upper edges of the lateral walls of the cavity and is continuous with the ependymal lining of the ventricle. It is covered by, and adherent to, a fold of pia mater, named the *tela chorioidea of the third ventricle*, from the under surface of which a pair of vascular fringed processes, named the *chorioid plexuses of the third ventricle*, project

downwards, one on each side of the median plane, and invaginate the epithelial roof into the ventricular cavity (fig. 909).

The *floor* (fig. 873) slopes downwards and forwards and is formed mainly by structures which belong to the hypothalamus; from before backwards these are: the optic chiasma, the infundibulum and tuber cinereum, and the corpora mamillaria. Behind the last-named, the floor is formed by the posterior perforated substance and by the tegmenta of the cerebral peduncles. The ventricle is prolonged downwards into the infundibulum as a funnel-shaped recess, termed the *infundibular recess*. The hypophysis is attached to the apex of the infundibulum.

The *anterior boundary* (fig. 873) is constituted below by the *lamina terminalis*, which represents the cephalic end of the primitive neural tube. It forms a thin layer of grey matter stretching from the upper surface of the optic chiasma to the rostrum of the corpus callosum. In its upper part the anterior boundary is formed by the columns of the fornix, which diverge as they pass downwards and sink into the lateral walls of the ventricle, and the anterior commissure (p. 1055), which crosses the median plane in front of them. At the junction of the floor and anterior wall, immediately above the optic chiasma, the ventricle presents a small angular recess or diverticulum, named the *optic recess*. Between the columns of the fornix, and above the anterior commissure, is a second recess, sometimes termed the *vulva*. At the junction of the roof with the anterior and lateral wall of the ventricle is the *interventricular foramen*, through which the third and the lateral ventricles communicate with one another. It represents the site of the original diverticular outgrowth from the telencephalon which forms the cerebral hemisphere, and is relatively large and circular in a 10 mm. human embryo. In the adult, however, it is reduced to a somewhat crescentic slit, bounded in front by the curving column of the fornix and behind by the convex anterior tubercle of the thalamus.

The *posterior boundary* (fig. 870) is constituted by the pineal body, the posterior commissure and the cerebral aqueduct. A small recess, named the *pineal recess*, projects into the stalk of the pineal body, whilst in front of and above the pineal body a second recess, named the *suprapineal recess*, consists of a diverticulum of the epithelium which forms the ventricular roof.

Each *lateral wall* consists of an upper portion formed by the medial surface of the anterior two-thirds of the thalamus, and a lower formed by the hypothalamus and continuous with the grey matter of the ventricular floor. These two parts are separated from each other by the *hypothalamic sulcus*, which extends from the interventricular foramen to the cerebral aqueduct, but is not always an obvious feature. The hypothalamic sulcus can be regarded as dividing the diencephalon into two main parts. Above the sulcus is the *pars dorsalis diencephali* consisting of the thalamus proper and the epithalamus. Below the sulcus is the *pars ventralis diencephali* which consists of the hypothalamus.* The lateral wall of the third ventricle is limited above by the ridge covering the stria medullaris thalami (p. 1001). The columns of the fornix curve downwards in front of the interventricular foramina, and then run in the lateral walls of the ventricle, where, at first, they form distinct prominences, but subsequently are lost to sight. The lateral walls are joined to each other across the cavity of the ventricle by a band of grey matter, named the *interthalamic adhesion* (p. 1001). The hypothalamus has been described on p. 1013.

The interpeduncular fossa (figs. 824, 875).—This is a somewhat lozenge-shaped area of the base of the brain, limited in front by the optic chiasma, behind by the anterosuperior surface of the pons, anterolaterally by the converging optic tracts and posterolaterally by the diverging cerebral peduncles. The structures contained in it have already been described; from behind forwards they are the posterior perforated substance (p. 1010), corpora mamillaria, tuber cinereum, infundibulum, and hypophysis (p. 1011).

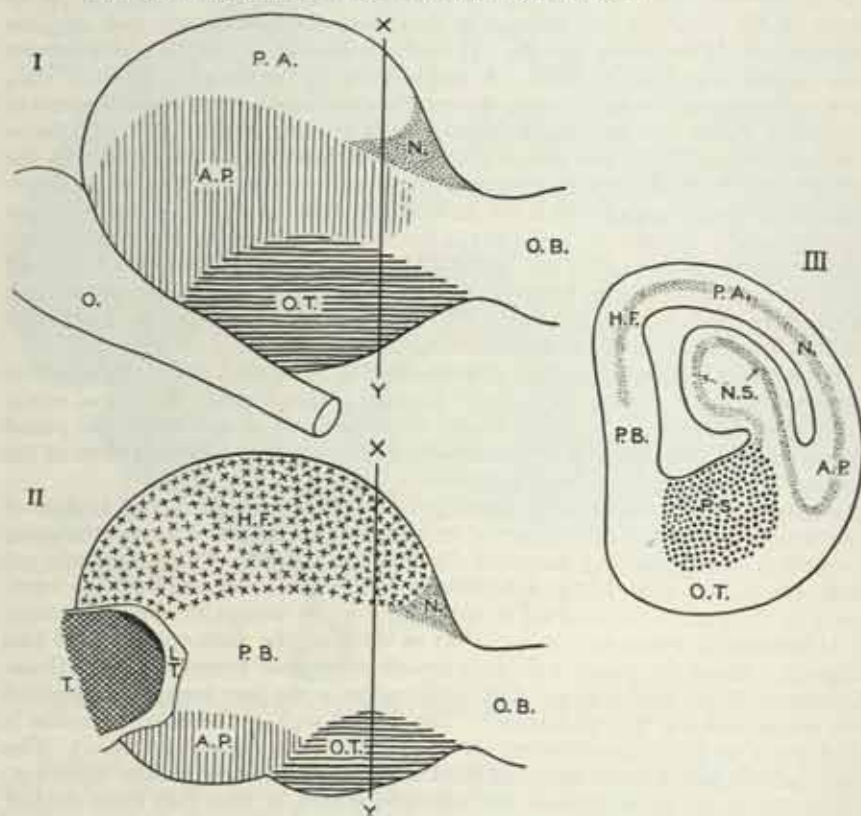
THE TELENCEPHALON

Introductory.—The expansion of the telencephalon and the development of the two cerebral hemispheres have already been described (p. 138). In the most primitive vertebrates the anterior part of each cerebral hemisphere is constricted to

* W. E. Le Gros Clark, *Brain*, 55, 1932.

form the *olfactory lobe*, which may become drawn forwards into a dilated extremity, termed the *olfactory bulb*. The latter is connected by a hollow stalk, named the *olfactory tract*, to an elevation on the wall of the hemisphere, termed the *olfactory tubercle*. In the basal part of each hemisphere a large nucleus is formed which derives its afferent fibres from the olfactory lobe and from the thalamus, and sends its efferent fibres to the brain-stem and the spinal medulla. This basal nucleus is termed the *palaeostriatum*, and it constitutes a centre where impulses from the olfactory bulb and the thalamus can be co-ordinated to influence the appropriate response. The remainder of the wall of the hemisphere constitutes the *pallium* or

FIG. 874.—Schematic representations of the cerebral hemisphere of a turtle, after Elliot Smith, *J. Anat.*, Lond. 53, 1919. (I) Lateral surface; (II) Medial surface; (III) Coronal section through I and II in the plane X Y.



A.P., area piriformis; H.F., hippocampal formation; L.T., lamina terminalis; N., neopallium; N.S., neostriatum; O., optic tract; O.B., olfactory bulb; O.T., olfactory tubercle; P.A., parahippocampal area; P.B., paraterminal body; P.S., palaeostriatum; T., thalamus.

mantle, which, in higher forms, becomes elaborated and expanded in a very remarkable manner.

In the lowest vertebrates the pallium shows very little differentiation, and it is merely a correlation area for gustatory impressions, which ascend from the hypothalamus, and for olfactory impressions, which stream into it from both olfactory lobes. Fibres from opposite sides cross in the lamina terminalis and represent the oldest commissures of the fore-brain, viz.: the anterior commissure and the commissure of the fornix.

In the reptilian brain (fig. 874) the pallium has undergone partial differentiation. On the medial wall of the hemisphere, immediately above the interventricular foramen, the *hippocampal formation* is established and the *piriform area* is laid down on the lateral wall, immediately adjacent to the palaeostriatum. The piriform area receives axons of the secondary olfactory neurones, which run from the olfactory bulb to the lateral surface of the hemisphere. New fibres from the thalamus invade the telencephalon and reach the pallium along the dorsal and ventral margins of the

piriform area. Those on the ventral margin preponderate at first, and the cells of the pallium in this situation multiply and grow centrally towards the cavity of the ventricle, in which they form a substantial longitudinal ridge. This ingrowth constitutes the *neostriatum*, which lies dorsal to the *palæostriatum* and intimately related to it. Prior to the invasion of the telencephalon by thalamic fibres the whole behaviour of the animal was dominated by olfactory impressions, but after its invasion by fibres conveying gustatory, visual, tactile and other forms of sensibility, modifying influences are introduced, and it becomes imperative that the activities of the *palæostriatum*—whatever they may be—should be regulated and, when necessary, inhibited. This controlling action seems to be exerted by the *neostriatum*.

At the same time other thalamic fibres reach the pallium along the dorsal and headward borders of the piriform area, and the cells in this situation increase enormously in number, and constitute the *neopallium*, as distinguished from the cortex of the hippocampal formation and the piriform area, which make up the *archipallium*. The cells of the *neopallium* lie between the hippocampal formation on the medial side and the piriform area on the lateral side.

In mammals the *neopallium* grows and expands, and in microsmatic animals, such as man, a part of this increase is accomplished at the expense of the *archipallium*, which is partly relegated to limited areas on the medial and basal surfaces of the cerebral hemisphere and is partly overlapped and buried. With the appearance of new sensory centres in the *neopallium*, the simple movements, which in lower vertebrates are initiated by the optic lobe, are insufficient to meet the demands and higher motor centres are therefore established in the *neopallium* for the control of the movements of the body. These motor centres are closely connected to the sensory centres in the *neopallium*, and as these connexions increase in number, behaviour becomes less and less affected by olfactory impressions and more and more influenced by other forms of sensibility.

At first the higher sensory centres laid down in the *neopallium* adjoin one another, but they gradually become separated by the development of association areas, in which at first visual, olfactory and gustatory impressions can be correlated. The interneuronal connexions between the areas which are predominantly concerned with these different forms of sensibility provide the mechanism for the registration of past experience, and so benefit the animal in its pursuit and selection of food and in many other ways. Its movements, therefore, become more purposive, and a plastic element is introduced into its behaviour.

The addition of higher auditory centres and the expansion of the somesthetic centres are accompanied by the appearance of new association areas, all of which become linked up with the motor centres as well as with the pre-existing sensory areas. As the *neopallium* expands for these purposes behaviour becomes still more purposive and plastic.

The association areas have reached a much higher degree of expansion in man than in his nearest relatives, the anthropoid apes, and it is this feature in the structure of the human brain that has rendered possible the complexities of the intellectual life.

The earlier stages of the expansion of the *neopallium* are the result of the process of *telencephalisation*, by means of which higher centres are shifted forwards into the end-brain. The best example of this process is the appearance of the visual cortex in the occipital lobe, which takes over the higher visual centres formerly situated in the optic lobe—superior colliculus of the mid-brain.

Parts of the telencephalon.—The telencephalon includes: (1) the cerebral hemispheres, the commissures which connect them, and the cavities which they contain, and (2) the anterior parts of the hypothalamus and of the third ventricle (already described on pp. 1009 and 1018). Each cerebral hemisphere consists of an outer layer of grey matter, termed the *cortex*, an inner mass of white fibres, and certain buried *basal nuclei*. The cortex may further be subdivided into the derivatives of the *neopallium* and of the *archipallium*. The latter, with certain outlying structures such as the olfactory bulb, constitutes the *rhinencephalon*.

THE CEREBRAL HEMISPHERES

The **cerebral hemispheres** form the largest part of the brain, and, when viewed together from above, assume the outline of an ovoid mass broader behind than in

front, the greatest transverse diameter corresponding with a line connecting the two parietal tuberosities. The hemispheres are incompletely separated by a deep median cleft, named the *longitudinal cerebral fissure*, and each possesses a central cavity, termed the *lateral ventricle*.

The *longitudinal fissure of the cerebrum* contains a sickle-shaped process of dura mater, named the *falx cerebri*, and the anterior cerebral vessels. In front and behind, the fissure completely separates the cerebral hemispheres from each other; in the middle, however, it only extends down to a great central white commissure, named the *corpus callosum*, which connects the hemispheres across the median plane.

THE SURFACES OF THE CEREBRAL HEMISPHERES

Each cerebral hemisphere presents three surfaces: convex, medial, and basal.

The *convex (superolateral) surface* is adapted to the concavity of the corresponding half of the vault of the cranium. The *medial surface* is flat and vertical and is separated from that of the opposite hemisphere by the longitudinal fissure and the falx cerebri. The *basal surface* is of an irregular form, and may be divided into two parts: orbital and tentorial. The orbital part, formed by the orbital surface of the frontal lobe, is concave, and rests on the roofs of the orbit and nose; the tentorial part is concavoconvex, and consists of the under surface of the temporal and occipital lobes; anterolaterally it is adapted to the corresponding half of the middle cranial fossa; posteromedially it rests upon the tentorium cerebelli, which intervenes between it and the upper surface of the cerebellum.

The three surfaces are separated by the following borders: (a) *superomedial*, between the convex and medial surfaces; (b) *inferolateral*, between the convex and basal surfaces; the anterior part of this border separates the superolateral from the orbital surface of the frontal lobe, and is known as the *superciliary border*; (c) *medial occipital*, between the tentorial and medial surfaces; and (d) *medial orbital*, separating the orbital from the medial surface. The anterior end of the hemisphere is named the *frontal pole*; the posterior, the *occipital pole*; and the anterior end of the temporal lobe, the *temporal pole*. About 5 cm. in front of the occipital pole on the inferolateral border there is an indentation or notch, named the *pre-occipital notch*.

A paramedian line, drawn, from a point a little above and lateral to the inion, forwards to a point just above and lateral to the nasion, corresponds to the superomedial margin. The superciliary border follows the curve of the eyebrows at a slightly higher level as far as the zygomatic process of the frontal bone and then ascends to the pterion. The temporal pole can be indicated on the surface of the head by a line drawn, with a forward convexity, from the pterion to the middle of the upper border of the zygomatic arch, and this line continued backwards just above the zygomatic arch and crossing the auricle a little above the external auditory meatus corresponds to the inferolateral margin of the hemisphere, which then curves downwards to reach the posterior end of the superomedial border (fig. 754).

The surfaces of the hemispheres are moulded into a number of irregular eminences, named *gyri* or *convolutions*, and separated by furrows termed *sulci*.

The irregular character of the surfaces of the cerebral hemispheres is a very prominent feature, but it must be remembered that up to the end of the fourth month these surfaces are smooth and unbroken, like the surfaces of the brains of reptiles and birds. Thereafter localised depressions become apparent, and they deepen and extend over the surface to form the sulci. Each sulcus corresponds to an infolding of the cortex so that the total amount of grey matter is nearly thirty times as much as might have been inferred from the surface area of the hemisphere. In certain situations the sulci develop along lines separating areas which differ from one another in the details of their microscopic structure and therefore probably in the functions which they predominantly subserve.* Such sulci may therefore be termed *limiting sulci*, since they establish the limits of certain functional areas. The central sulcus is an admirable example of a limiting sulcus, for it is set between two areas of cortex which differ in thickness so notably that the difference can be appreciated with the naked eye (fig. 879). In other situations sulci develop in the long axis of a rapidly growing homogeneous area and are termed *axial sulci*. The posterior

* W. E. Le Gros Clark in *Essays on Growth and Form*, Oxford, 1945.

part of the calcarine sulcus is situated in the centre of the striate area of the cortex and is related on both sides to the higher visual centres. In other situations, again, a sulcus may be situated between two surface areas of cortex which are structurally different, but its lip and not its floor may form the dividing line between the two areas. In these cases a third area is present in the wall of the sulcus and does not appear on the surface at all. Such a sulcus is termed an *operculated sulcus*, and this type is represented in the human brain by the lunate sulcus, which separates the striate from the peristriate areas on the surface and contains in its wall the submerged parastriate area, which really intervenes between them. These three varieties include all the sulci which develop on the surface of the brain, with the exception of the lateral sulcus and the parieto-occipital sulcus. The former is the result of the slower expansion of the cortex of the insula and its consequent submersion by the adjoining cortical areas, which eventually come into contact with one another so as to delimit the lateral sulcus. The latter is brought about subsequent to the development of the corpus callosum. The posterior end of this great commissure has to convey not only the fibres from the occipital portions of the brain but also a large number of fibres from the temporal portions. As a result, a number of smaller axial and limiting sulci become crowded together and some of them become buried within the walls of the parieto-occipital sulcus. These two are really secondary sulci, since their occurrence depends on factors other than exuberant growth in closely adjoining areas.

Some of the sulci which indent the hemisphere are deep enough to produce corresponding elevations in the walls of the lateral ventricles. The anterior part of the calcarine sulcus, which produces the calcar avis of the posterior horn, and the collateral, which produces the collateral eminence in the inferior horn, are therefore termed *complete sulci*. There is, however, no special morphological or functional significance to be attached to the fact that while some sulci are complete others are incomplete.

The gyri and their intervening sulci are fairly constant in their arrangement; at the same time they vary within certain limits, not only in different individuals, but in the two hemispheres of the same brain. The convoluted condition of the surface permits of a great increase of the grey matter without the sacrifice of much additional space, and the number and extent of the gyri, as well as the depth of the intervening furrows, appear, within broad limits, to bear a direct relation to the intellectual powers of the individual.

At this stage a brief survey must be made of the topographical anatomy of the cerebral hemispheres, before the structure of the cortex and the functional significance of its various areas can profitably be discussed.

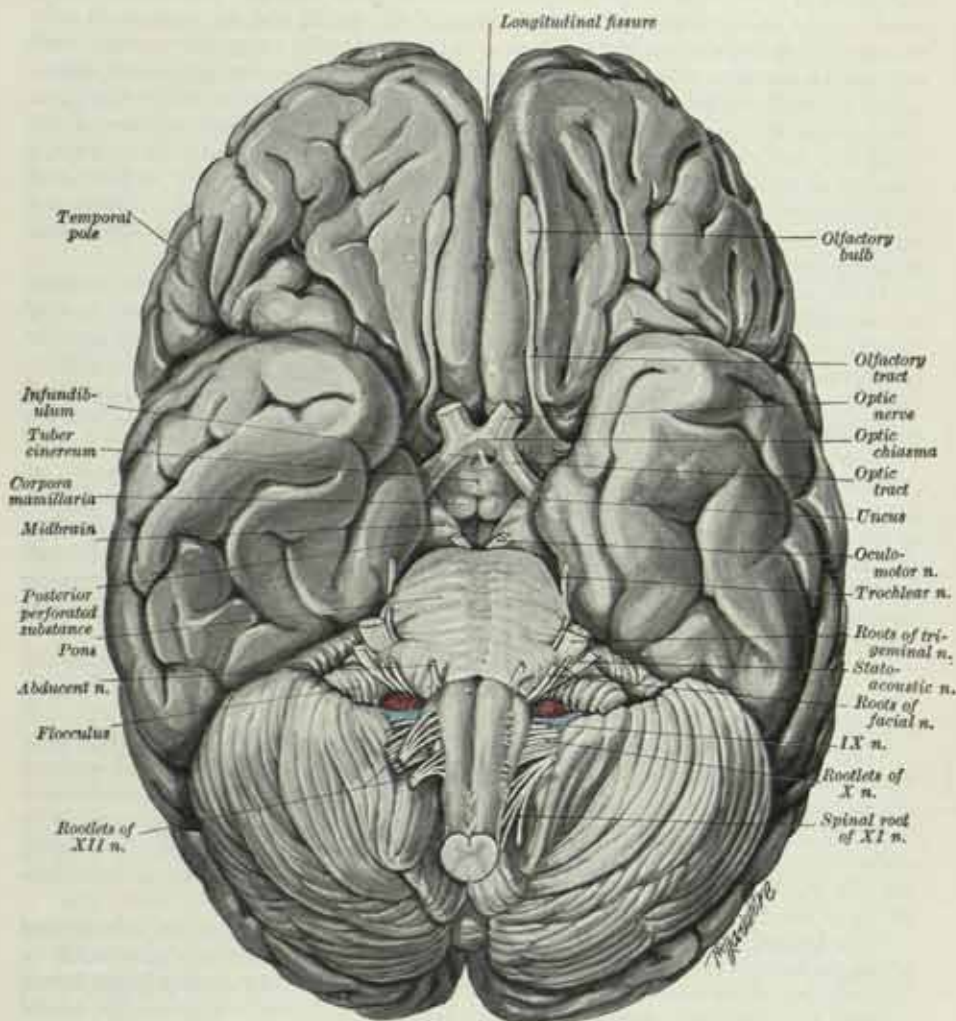
The convex (superolateral) surface of the cerebral hemisphere (figs. 876, 877).—It is convenient for ease of description and for ease of reference to separate this surface into a number of lobes, but it must be remembered that this subdivision is purely one of convenience and that the lobes do not precisely correspond in surface extent to the cranial bones from which their names are derived. Two sulci, viz. the *lateral sulcus* and the *central sulcus*, take a large part in forming the boundaries of the lobes into which this surface is divided.

The **lateral sulcus** (figs. 875 and 876) is a deep cleft situated on the inferior and lateral surfaces of the cerebral hemisphere. It consists of a short stem which ends by dividing into three rami. The *stem* commences on the inferior surface at the lateral angle of the anterior perforated substance and extends laterally between the orbital surface of the frontal lobe and the anterior part of the temporal lobe. It is occupied by the free posterior border of the lesser wing of the sphenoid bone. On reaching the lateral surface it divides into anterior horizontal, anterior ascending and posterior rami. The *anterior ramus* runs forward for 2.5 cm. or less into the inferior frontal gyrus, while the *ascending ramus* runs upwards for about an equal distance into the same gyrus. The *posterior ramus* is the longest division. It courses backwards and slightly upwards across the lateral surface for about 7 cm. before turning upwards to end in the parietal lobe. The floor of this sulcus is formed by the *limen insulæ* and the *insula*, and it conducts the middle cerebral vessels from the basal to the lateral aspect of the hemisphere. It can be represented on the side of the head by a line drawn backwards and slightly upwards for 7 cm. from the pterion and then curving upwards to end under the parietal eminence.

The **central sulcus** (fig. 876) commences in or near the superomedial margin

of the hemisphere a little behind the mid-point between the frontal and occipital poles. It runs sinuously downwards and forwards and ends a little above the posterior ramus of the lateral sulcus, from which it is always separated by an arched gyrus. The general direction of the sulcus makes an angle of rather less than 70° with the median plane and its lower end lies 5 cm. vertically above the pre-auricular point (fig. 754). The central sulcus is a good example of a typical limiting sulcus, for it develops along the line which separates the motor area of the cerebral cortex from the somesthetic area (p. 1044).

FIG. 875.—The base of the brain.



Note.—The anterior perforated substance is hidden by the diverging lateral and medial roots of the olfactory tract and is anterolateral to the optic tract of each side.

When the central sulcus is opened up, the opposed walls are found to be marked by a number of small gyri which interlock with one another after the manner of gears in mesh, and are therefore termed *interlocking gyri*. This arrangement provides additional cortical grey matter without any corresponding increase in the surface area of the hemisphere. Another feature is brought to light by opening up the sulcus. The floor is not the same depth throughout its whole extent, for a little below the middle of the sulcus its walls are usually connected to each other by a buried, transverse gyrus. The explanation of this condition is found in the mode of development of the central sulcus. When it makes its appearance in the sixth month, it does so in two distinct portions, an upper and a lower, which are at first

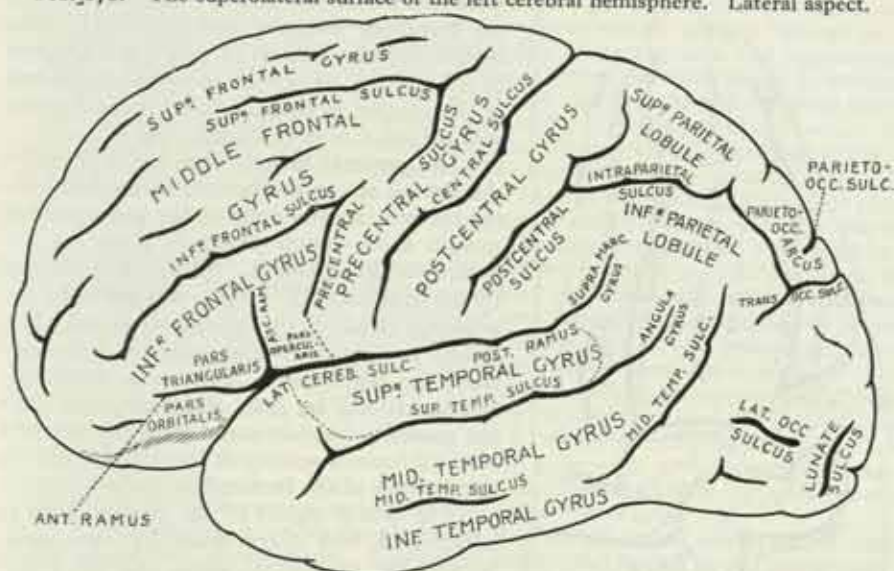
separated by a transverse gyrus connecting the precentral convolution to the post-central. The two parts occasionally remain separate, but as a rule they run into each other, and the transverse gyrus becomes buried as a *deep transitional gyrus*.

The anterior part of the hemisphere is termed the **frontal lobe**, and it comprises the whole of the area which lies in front of the central sulcus and above the lateral sulcus. It is limited above by the superomedial and below and in front by the superciliary margin of the hemisphere.

The lateral surface of the frontal lobe is traversed by three sulci which divide it into four gyri. The *precentral sulcus* runs parallel to the central sulcus, and is separated from it by the precentral gyrus. It is usually divided into upper and lower parts, but the two may be confluent. The *superior frontal sulcus* runs forwards and downwards from about the middle of the upper part of the precentral sulcus, while the *inferior frontal sulcus* runs parallel to it at a lower level. The portion of the frontal lobe which lies anterior to the precentral sulcus is thus divided into the superior, middle and inferior frontal gyri.

The *precentral gyrus*, which is bounded behind by the central sulcus and in front by the precentral sulcus, extends from the superomedial border of the hemisphere

FIG. 76.—The superolateral surface of the left cerebral hemisphere. Lateral aspect.



to the posterior ramus of the lateral sulcus. Its large pyramidal cells give origin to some of the fibres of the important corticonuclear and corticospinal (pyramidal) motor tracts (p. 1041).

The *superior frontal gyrus* lies above the superior frontal sulcus, and is continuous over the superomedial margin of the hemisphere with the medial frontal gyrus on the medial surface. It is more or less completely subdivided into upper and lower portions by the paramedian sulcus which, however, is frequently interrupted by bridging gyri.

The *middle frontal gyrus* lies between the superior and the inferior frontal sulci. Its surface is broken by two or three small sulci which together constitute the *middle frontal sulcus*. Lesions of the posterior part of this gyrus result in interference with conjugate movements of the eyes (p. 1042).

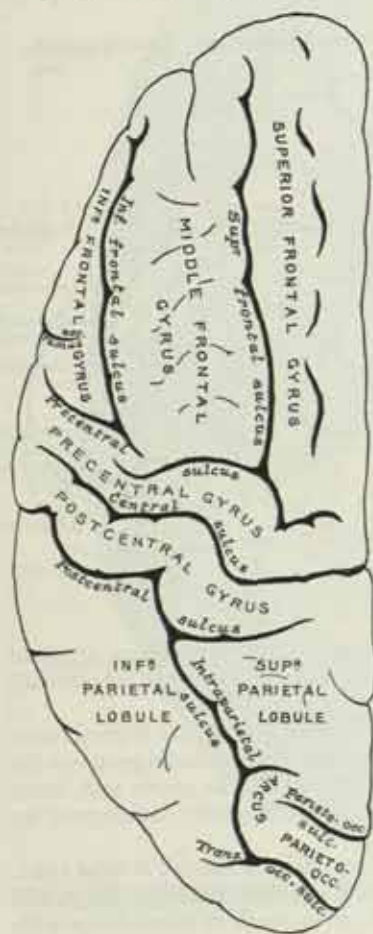
The *inferior frontal gyrus* lies below the inferior frontal sulcus and is invaded by the anterior and ascending rami of the lateral sulcus. The areas grouped around these two rami constitute *Broca's area* and are associated with the motor element of speech (p. 1043). The portion lying below the anterior ramus is termed the *pars orbitalis*, and it curves round the superciliary margin to gain the orbital surface of the frontal lobe. The portion between the ascending and the anterior rami is termed the *pars triangularis*, while the portion lying behind the ascending ramus forms the *pars opercularis* (posterior) and is continuous behind with the lowest part of the precentral gyrus.

The **temporal lobe** lies below the lateral sulcus. Behind, it is limited by an arbitrary line drawn from the preoccipital notch (p. 1022) to the parieto-occipital sulcus, where it cuts the superomedial margin about 5 cm. in front of the occipital pole. The lateral surface of the temporal lobe is divided into three parallel gyri by two sulci.

The **superior temporal sulcus** begins behind the temporal pole and runs backwards and slightly upwards parallel to the posterior ramus of the lateral sulcus. Its posterior end curves upwards into the parietal lobe. The **inferior temporal sulcus** lies below and parallel to the superior sulcus. It is broken up into two or three short sulci, but its posterior end turns upwards into the parietal lobe, behind and parallel to the upturned end of the superior sulcus.

In this way the lateral surface of the temporal lobe is subdivided into three parallel gyri, the **superior**, **middle** and **inferior temporal gyri**. Along its upper margin

FIG. 877.—The superolateral surface of the left cerebral hemisphere. Superior aspect.



the superior temporal gyrus is continuous with the gyri which form the floor of the posterior ramus of the lateral sulcus. These are three or four in number, and they extend obliquely forwards and laterally from the circular sulcus which surrounds the insula. They are termed the **transverse temporal gyri** (fig. 878). The higher auditory centres (p. 1047) are situated in the anterior transverse temporal gyrus and in the portion of the superior temporal gyrus with which it is in continuity (fig. 888).

The **parietal lobe** is bounded in front by the central sulcus and behind by the line joining the preoccipital notch to the superomedial margin at the point where it is cut by the parieto-occipital sulcus. Above, it is limited by the superomedial margin, and below by the posterior ramus of the lateral sulcus and a line drawn backwards to the posterior boundary from the point where the ramus turns upwards. It will be seen, therefore, that both the posterior boundary and the posterior part of the inferior boundary of the parietal lobe on this surface of the hemisphere are arbitrary.

The lateral aspect of the parietal lobe is subdivided into three areas by two sulci, termed the **postcentral sulcus**, and the **intraparietal sulcus**.

The **postcentral sulcus** (fig. 876), which may be divided into upper and lower parts, lies behind and parallel to the central sulcus. Inferiorly it ends above the posterior ramus of the lateral sulcus and in front of its upturned end. It divides the parietal lobe into an anterior part, termed the **postcentral gyrus**, and a large posterior part which is further subdivided by the **intraparietal sulcus**. The **intraparietal sulcus** commences in the postcentral sulcus about its middle or at the upper end of its lower subdivision. It extends back-

wards and downwards across the posterior part of the parietal lobe, dividing it into a superior and an inferior parietal lobule. Posteriorly, as the occipital ramus, it extends into the occipital lobe, where it joins the transverse occipital sulcus at right angles (fig. 877).

The **postcentral gyrus** lies between the central sulcus in front and the post-central sulcus behind. It contains the important higher centres for somesthetic sensibility (p. 1044).

The **superior parietal lobule** lies between the superomedial margin of the hemisphere and the intraparietal sulcus. In front, it is continuous with the postcentral

gyrus round the upper end of the postcentral sulcus, while posteriorly it frequently runs into the arcus parieto-occipitalis, which surrounds the external part of the parieto-occipital sulcus (fig. 877).

The *inferior parietal lobule* lies below the intraparietal sulcus and behind the lower part of the postcentral sulcus. It is divided into three parts. The *anterior part* is termed the *supramarginal gyrus* and arches over the upturned end of the lateral sulcus; it is continuous in front with the lower part of the post-central gyrus and below and behind with the superior temporal gyrus. Occasionally it is limited posteriorly by a small sulcus, named the *sulcus intermedius primus*, which descends from the intraparietal sulcus. The *middle part* or *angular gyrus*, which is believed to be concerned with the visual element in stereognosis (p. 1047), arches over the upturned end of the superior temporal sulcus and is continuous behind and below with the middle temporal gyrus; sometimes a small sulcus *intermedius secundus* forms its posterior boundary. Both the anterior and middle parts of the inferior parietal lobule lie under the parietal eminence (p. 269). The *posterior part* arches over the upturned end of the inferior temporal sulcus and extends on to the occipital lobe.

The part of the lateral surface which lies behind the line joining the preoccipital notch to the parieto-occipital sulcus on the superomedial margin belongs to the **occipital lobe**. The *transverse occipital sulcus* descends from the superomedial margin behind the parieto-occipital sulcus and is joined about its middle by the intraparietal sulcus. Its upper portion forms the posterior boundary of the *arcus parieto-occipitalis*, an arched gyrus which surrounds the end of the parieto-occipital sulcus. The *lateral occipital sulcus* is a short sulcus which runs forwards on the lateral aspect of the occipital lobe and divides it into a *superior* and an *inferior occipital gyrus* (fig. 876). The *sulcus lunatus*, when present, is situated just in front of the occipital pole. It is placed vertically and sometimes forms a T with the calcarine sulcus, although the two are more often separated from each other. The lips of the lunate sulcus, which is operculated in type, separate the striate from the peristriate area of the cortex, but the parastriate area is buried within the walls of the sulcus and intervenes between them. The lunate sulcus forms the posterior boundary of the *gyrus descendens* (Ecker), which lies behind the superior and inferior occipital gyri. Two curved sulci, named the superior and inferior polar sulci, are often present near the extremities of the lunate sulcus. The *superior polar sulcus* arches upwards on to the medial aspect of the occipital lobe from the neighbourhood of the upper limit of the lunate sulcus; the *inferior polar sulcus* arches downwards and forwards on to the inferior aspect from the lower limit of the same sulcus. These two polar sulci enclose semilunar extensions of the striate area (p. 1045) and indicate the expansion of the visual cortex associated with the formation of its large macular area* (p. 1046).

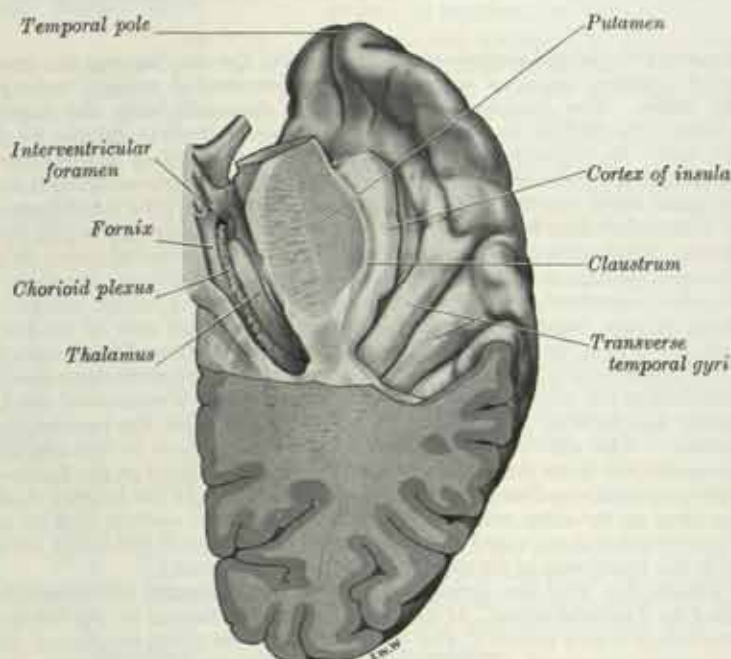
The **insula** (fig. 879) lies deeply in the floor of the lateral sulcus and is almost surrounded by a *circular sulcus*. It has been hidden and buried by the overgrowth of the cortical areas which adjoin it, and it can only be seen when the lips of the lateral sulcus are widely separated. These areas of the cortex are therefore termed the *opercula of the insula*, and they are separated from each other by the ascending and posterior rami of the lateral sulcus. The *frontal operculum* lies between the anterior and ascending rami, and is formed by the pars triangularis of the inferior frontal gyrus. It may be of small size in cases where the two rami between which it lies arise by a common stem. The *fronto-parietal operculum* lies between the ascending and the upturned end of the posterior ramus of the lateral sulcus. It is formed by the pars posterior of the inferior frontal gyrus, by the lower ends of the precentral and post-central gyri, and by the lower end of the anterior part of the inferior parietal lobule. The *temporal operculum* lies below the posterior ramus and is formed by the superior temporal gyrus and the transverse temporal gyri. Anteriorly the lower part of the insula adjoins the pars orbitalis of the inferior frontal gyrus.

When the opercula have been removed, the insula is seen as a pyramidal eminence, the apex of which is directed towards the anterior perforated substance (fig. 879). In this situation the circular sulcus is deficient and the medial part of the apex is termed the *limen insulae*. The surface of the insula is divided into a larger anterior and a smaller posterior part by the *sulcus centralis insulae*, which runs upwards and backwards from the apex of the insula. The anterior part is divided by shallow sulci into three or four *short gyri*, while the posterior part is formed by one *long gyrus*, which is often divided at its upper end. The cortical grey matter of the insula is continuous with that of the various opercula round the bottom of the circular sulcus. The insula overlies, and is more or less co-extensive with the claustrum and the putamen of the lentiform nucleus (fig. 878).

* G. Elliot Smith, *J. Anat.*, Lond., 64, 1930.

The medial surface of the cerebral hemisphere.—This surface cannot be examined until the two cerebral hemispheres have been separated from each other by the division of (1) the commissures which connect them and (2) the roof, floor, anterior and posterior walls of the third ventricle (fig. 870). The most conspicuous feature on this surface is the great commissure which is termed the *corpus callosum*. It forms a broad arched band which lies in the floor of the central part of the longitudinal fissure (fig. 880). The recurved, anterior end of the corpus callosum is termed the *genu*. Below, it is continuous with the *rostrum*, which narrows rapidly as it passes backwards to become connected to the upper end of the lamina terminalis; above, it is continuous with the *trunk*, which arches upwards and backwards to end in a thickened, rounded extremity, termed the *splenium*. The deep surfaces of the trunk, genu and rostrum give attachment to the laminae of the septum pellucidum, which occupies the interval between them and the fornix—a curved, flattened band

FIG. 878.—A section showing the upper surface of the right temporal lobe.



of fibres which lies at a lower level. Immediately in front of the lamina terminalis and almost co-extensive with it, there is a narrow, triangular field of grey matter, which is termed the *paraterminal gyrus* (p. 1035). Anteriorly it is separated from the rest of the cortex by a shallow groove, named the *posterior parolfactory sulcus*. A little in front of this groove a second, short, vertical sulcus may be present and is termed the *anterior parolfactory sulcus*. The portion of cortex which lies between these two sulci constitutes the *subcallosal area* (*parolfactory*) (figs. 879, 873).

The anterior part of the medial surface of the hemisphere is divided into an outer and an inner zone by a curved sulcus, termed the *sulcus cinguli*. It commences below the rostrum of the corpus callosum and passes first forwards, then upwards and finally backwards, conforming with the curvature of the corpus callosum. Its posterior end turns upwards to reach the superomedial margin of the hemisphere, about 4 cm. behind the mid-point between the frontal and occipital poles, and lies behind the upper extremity of the central sulcus (fig. 880). The outer zone demarcated by the sulcus cinguli forms, with the exception of its extreme posterior end, a part of the frontal lobe. It is subdivided into a larger anterior portion and a smaller posterior portion by a short fissure which runs upwards from the sulcus cinguli above the middle of the trunk of the corpus callosum. The larger anterior portion is the *medial frontal gyrus*, while the smaller posterior portion is termed the *paracentral lobule*. The upper end of the central sulcus usually cuts into the posterior part of

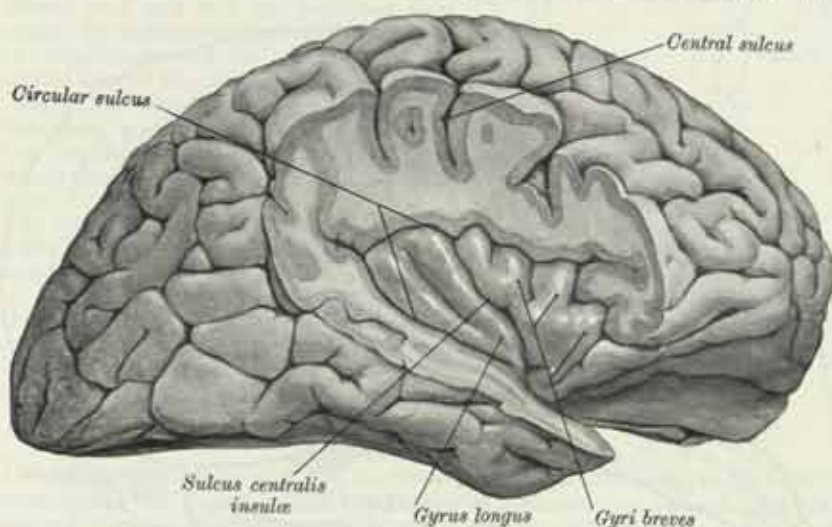
the paracentral lobule and the motor cortex of the precentral gyrus is directly continuous with the cortex of the lobule. This area contains the centres which control the movements of the lower limb and perineal region of the opposite side, and clinical evidence suggests that it exercises voluntary control over the defæcation and micturition reflexes (p. 1041).

The inner zone which is marked off by the sulcus cinguli constitutes the *gyrus cinguli*. Commencing below the rostrum this gyrus follows the curve of the corpus callosum, from which it is separated by the *callosal sulcus*, and it continues round the splenium on to the inferior surface of the hemisphere to become continuous with the parahippocampal gyrus through the narrow *isthmus* (fig. 88o). It is connected with the anterior nucleus of the thalamus by both afferent and efferent pathways.

The line of the sulcus cinguli is interrupted behind the paracentral lobule, but is partially continued by a short sulcus, of variable form, termed the *subparietal* (*suprasplenic*) *sulcus*.

The posterior part of the medial surface of the hemisphere is marked by two

FIG. 879.—The insula of the right side. Exposed by the removal of the opercula.



deep sulci which converge anteriorly and meet a short distance behind the splenium of the corpus callosum. These are the parieto-occipital and the calcarine sulci. The *parieto-occipital sulcus* commences on the superomedial margin of the hemisphere about 5 cm. in front of the occipital pole and is directed downwards and slightly forwards to meet the calcarine sulcus. When the lips of the sulcus are widely separated it will be found that, although on the surface of the hemisphere the parieto-occipital and the calcarine sulci are apparently continuous, they are in reality separated from each other by a buried gyrus, termed the *gyrus cuneus*. In addition, the walls of the sulcus show the presence of two or more vertically disposed sulci. These sulci were originally exposed on the medial surface of the hemisphere, but they became buried and included in the parieto-occipital sulcus owing to the growth of the splenium of the corpus callosum (p. 1023). The walls of the parieto-occipital sulcus, therefore, resemble the walls of the lateral sulcus, although the contained sulci and gyri are fewer in number and smaller in extent.

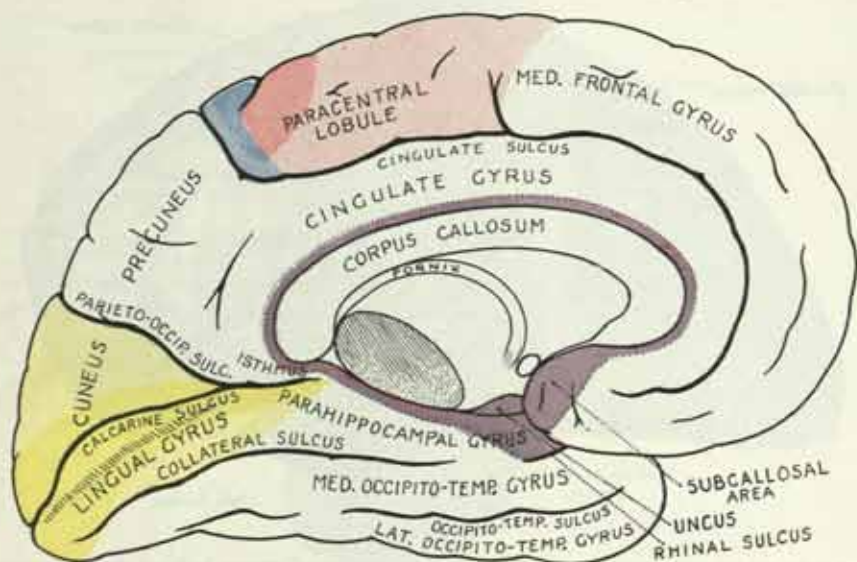
The *calcarine sulcus* commences in the neighbourhood of the occipital pole. Although the sulcus is usually restricted to the medial surface of the hemisphere its posterior end occasionally extends on to the lateral surface. It runs forwards a little above the inferomedial margin of the hemisphere, taking a slightly curved course with an upward convexity, and joins the parieto-occipital sulcus at an acute angle a little behind the splenium of the corpus callosum. Continuing forwards the calcarine sulcus crosses the inferomedial margin and gains the inferior aspect of the hemisphere, where it forms the inferolateral boundary of the *isthmus*, which con-

nects the gyrus cinguli with the parahippocampal gyrus. At its junction with the parieto-occipital sulcus the floor of the calcarine sulcus is crossed by the buried anterior cuneolingual gyrus. The posterior part of the calcarine sulcus, behind its junction with the parieto-occipital is an axial sulcus, set in the long axis of the visual cortex (p. 1045) whilst the anterior part is a limiting sulcus and separates the striate, visual cortex from that of the isthmus. The anterior part conforms to the definition of a complete sulcus, since it produces an elevation in the medial wall of the posterior horn of the lateral ventricle (the calcar avis).

The quadrilateral area, bounded in front by the upturned end of the sulcus cinguli, behind by the parieto-occipital sulcus, above by the superomedial margin and below by the suprasplenial sulcus, is termed the *precuneus* and, together with the part of the paracentral lobule which lies behind the central sulcus, constitutes the medial surface of the parietal lobe.

The wedge-shaped area bounded in front by the parieto-occipital sulcus, below by the calcarine sulcus and above by the supero-medial margin, is termed the *cuneus*. Its surface is usually indented by one or two small irregular sulci, and forms the medial surface of the occipital lobe.

FIG. 880.—The medial surface of the left cerebral hemisphere.



Note.—The broadly shaded line, running upwards and forwards from the occipital pole represents the position of the infero-medial border of the hemisphere.

The basal (inferior) surface of the cerebral hemisphere (figs. 875, 883).—

This surface is subdivided into a smaller, anterior portion, which lies in front of the stem of the lateral fissure, and a larger, posterior portion, which lies behind it. The anterior portion forms the *orbital surface of the cerebral hemisphere*. It is concave from side to side and rests on the cribriform plate of the ethmoid bone, the orbital plate of the frontal bone and the lesser wing of the sphenoid bone. An anteroposterior sulcus traverses this surface near its medial margin and, since it is hidden by the overlying olfactory bulb and tract, it is termed the *olfactory sulcus*. The medial strip of cortex which it marks off is the *gyrus rectus*. The rest of this surface is marked by irregular sulci, the *orbital sulci*, generally H-shaped, dividing it into a number of *orbital gyri*. Four can usually be recognised, named, according to their position, anterior, medial, posterior and lateral orbital gyri. The posterior orbital gyrus (*area 13*) is regarded as exercising a controlling influence on visceral activity (p. 1049).

The posterior portion forms the *tentorial surface* of the hemisphere, and rests partly on the tentorium cerebelli and partly on the floor of the middle cranial fossa. It is traversed by two anteroposterior sulci, the collateral and the occipitotemporal. The *collateral sulcus* commences near the occipital pole and runs forwards, roughly parallel to the calcarine sulcus, from which it is separated by the *lingual gyrus*. Anteriorly the collateral sulcus may be continued into the *rhinal sulcus*, but the two are usually separated. The *rhinal sulcus* runs forwards in the line of the collateral

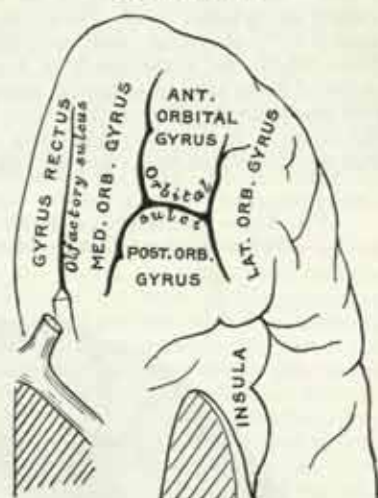
sulcus and separates the temporal pole from a somewhat hook-shaped elevation which lies posteromedial to it and is termed the *uncus*. This fissure marks the lateral limit of the piriform area of the cortex (p. 1033).

The *occipitotemporal sulcus* lies parallel to the collateral sulcus and on its lateral side. As a rule it does not extend as far back as the occipital pole, and it is frequently divided into two or more parts.

The *lingual gyrus* lies between the calcarine and the collateral sulci. Anteriorly it passes without interruption into the *parahippocampal gyrus*, which commences at the *isthmus*, where it is directly continuous with the gyrus cinguli, and passes forwards bounded on its lateral side by the collateral and rhinal sulci. Anteriorly the parahippocampal gyrus becomes continuous with the *uncus*, and as it passes forwards its medial edge abuts on the side of the mid-brain. The *uncus* is the recurved, hook-like, anterior end of the parahippocampal gyrus and forms the posterolateral boundary of the anterior perforated substance. The medial part of its hook extends laterally above its lateral part and will be described later (p. 1033); its inferior surface cannot be exposed completely until the lateral and more superficial part of the hook has been removed (fig. 883). The *uncus* forms the bulk of the *piriform area*, which constitutes an important part of the rhinencephalon (p. 1033) and is phylogenetically one of the oldest parts of the pallium.

The *medial occipitotemporal gyrus* extends from the neighbourhood of the occipital to the temporal pole. It is limited by the collateral and rhinal sulci on its medial side and by the occipitotemporal sulcus on its lateral side. The lateral part of this area forms the *lateral occipitotemporal gyrus*, which is continuous round the inferolateral margin of the hemisphere with the inferior temporal gyrus.

FIG. 881.—The orbital surface of the left frontal lobe.



THE RHINENCEPHALON

The **rhinencephalon** includes all those portions of the cerebrum which are concerned with the reception and conduction of olfactory impressions. In lower vertebrates the rhinencephalon consists of the olfactory lobe and the archipallium, and includes nearly the whole of the fore-brain. In man, however, the archipallium has been so much reduced by the exuberant growth of the neopallium that many of its derivatives are difficult to recognise with the naked eye. They have been relegated to the medial and inferior surfaces; some have become thinned out into a fine sheet by the growth of the corpus callosum (p. 1052), while others have been overgrown and buried by the development of neighbouring neopallial areas.

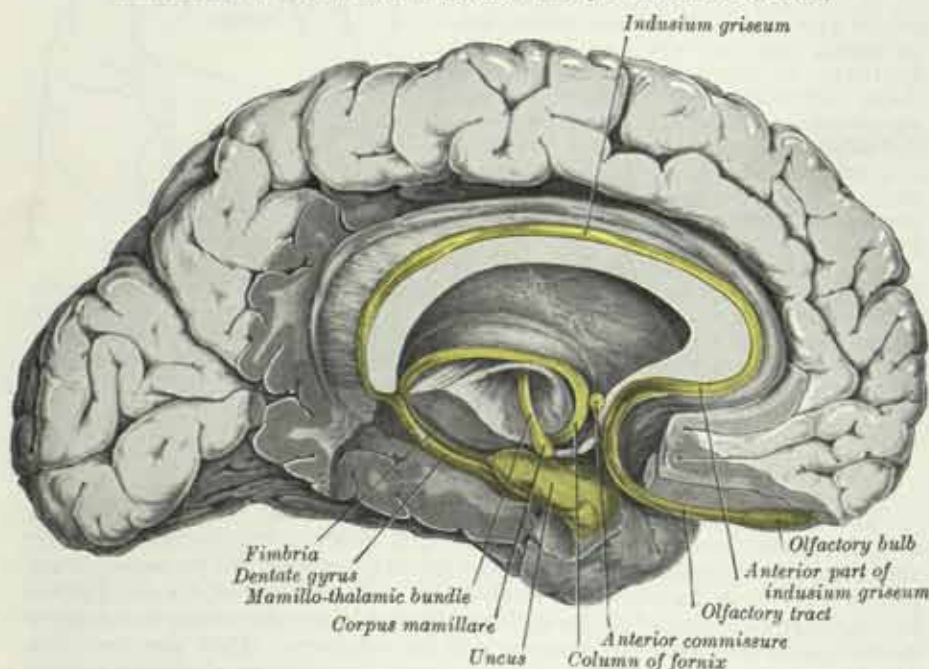
The constituent parts of the rhinencephalon are: (1) the *olfactory bulb*, in which the primary olfactory neurones end and the secondary neurones begin, (2) the *olfactory tract*, which conveys the secondary olfactory neurones to (3) the *anterior perforated substance*, the *amygdaloid body* (p. 1033) and the *area piriformis*, (4) the *hippocampal formation*, (5) the *paraterminal gyrus*, (6) the *fornix*, which constitutes the efferent pathway from the hippocampal formation and the archipallium in general, and (7) the *nucleus habenulae*. The part played by the hippocampus and the fornix in the activities of the rhinencephalon and their other functional relationships are discussed on p. 1034.

(1) The **olfactory bulb** (see also p. 1050) is an oval, reddish-grey mass which lies above the medial edge of the orbital plate of the frontal bone and below the anterior end of the olfactory sulcus on the orbital surface of the frontal lobe. The olfactory nerves pass upwards through the cribriform plate from the olfactory region of the nasal mucous membrane and enter its inferior surface.

(2) The **olfactory tract** is a narrow, white band which issues from the posterior end of the olfactory bulb and passes backwards on the orbital surface of the frontal lobe, covering the olfactory sulcus. On transverse section it is triangular in outline,

the apex being directed upwards. At its expanded posterior end, which is termed the *olfactory trigone* (olfactory pyramid) the tract is inserted into the cerebrum. Behind this trigone is the anterior perforated substance. Passing backwards along the anterior margin of the anterior perforated substance, where its fibres are usually detected with the naked eye, is the *olfactory stria* (lateral root of the olfactory tract). On reaching the *limen insulae* (p. 1027) it bends sharply backwards and medially in the floor of the stem of the lateral sulcus and enters the superolateral part of the uncus. It contains the axons of the mitral cells of the olfactory bulb and is accompanied by grey matter; its fibres terminate in the anterior part of the piriform area and in the adjoining amygdaloid body. Some fibres from the olfactory tract (medial root), accompanied by grey matter, pass medially from the olfactory trigone to the paraterminal gyrus which lies immediately in front of the lamina terminalis. It is believed that many of these arise in scattered masses of cells which lie along the olfactory tract and that few primary olfactory neurones, from the mitral cells in the olfactory bulb, take this route.* A few fibres, probably of a similar origin (intermediate root of the olfactory tract) also pass back from the olfactory trigone to the anterior perforated substance.

FIG. 882.—A dissection of the left cerebral hemisphere, showing the parts of the rhinencephalon. Drawn from a specimen lent by Professor R. B. Green.



Note.—This figure illustrates the old concept of the rhinencephalon, which has been materially modified by recent experimental work (p. 1024).

(3) (a) The **anterior perforated substance**, which lies in the angle between the optic tract and the uncus, is an important landmark on the basal surface of the cerebral hemisphere. In front it is bounded by the olfactory trigone and the olfactory stria. Medially it is continuous, above the optic tract, with the tuber cinereum and, in front of that, with the lower end of the paraterminal gyrus. Laterally it extends to the *limen insulae* (p. 1027). It is pierced by the central branches of the anterior and middle cerebral arteries and its exposed surface is crossed by the latter vessel. Superiorly it is continuous with the grey matter of the corpus striatum and of the claustrum, and it is separated from the anterior part of the globus pallidus by the anterior commissure, the ansa lenticularis and the ansa peduncularis (pp. 1003 and 1066). In the cat electrical stimulation of this and the adjoining basal olfactory areas gives rise to a number of reactions. These include sniffing, salivation, movements of the tongue, mouth and mandible, retching and swallowing.†

* A. C. Allison, *J. Anat. Lond.*, **88**, 1954.

† D. McK. Rioch and C. Brenner, *J. Comp. Neur.*, **68**, 1938.

(b) The **amygdaloid body (nucleus)** is a complex nuclear mass lying above and in front of the inferior horn of the lateral ventricle. It is continuous above with the cortex of the uncus, in front with the limen insulae and above and laterally with the anterior perforated substance. Posteriorly it appears to become continuous with the tail of the caudate nucleus (p. 1065). It receives *afferent* fibres from the olfactory* tract, and its *efferents* pass posteriorly in the roof of the inferior horn of the lateral ventricle, forming a small bundle termed the *stria terminalis* (fig. 884).

The *stria terminalis (semicircularis)* is a small collection of medullated nerve-fibres which issues from the posterior end of the amygdaloid body† and runs backwards in the roof of the inferior horn of the lateral ventricle on the medial side of the tail of the caudate nucleus. It follows the curve of the nucleus and runs forwards in the floor of the central part of the ventricle, occupying the groove which separates the caudate nucleus from the thalamus. Below the interventricular foramen it gives off some fibres to the anterior commissure, and to the grey matter of the anterior perforated substance, and turns downwards to enter the hypothalamus (fig. 884), where it ends by sending fibres to several of the hypothalamic nuclei. It may therefore be regarded as a pathway for the association of the olfactory and autonomic systems.

(c) The **piriform area** includes the anterior perforated substance, the grey matter extending from this through the limen insulae to the uncus, the uncus itself and the anterior part of the parahippocampal gyrus. Many, if not most of the secondary olfactory neurones end in the anterior part of the area and are here related to incoming fibres from other parts of the cortex. It is reasonable to assume that in this part of the cortex olfactory impressions reach consciousness and the tertiary neurones pass to the posterior part of the area (*area 28*), to be correlated and integrated with other afferent impressions. When the lateral part of the uncus is removed, the inferior surface of its medial part can be examined. It is crossed about its middle by a narrow band of grey matter, continuous at its lateral end with the dentate gyrus, and termed the *tail of the dentate gyrus* (fig. 883). The portion of the uncus which lies behind the tail of the dentate gyrus has been termed the *intralimbic gyrus*, and it is morphologically distinct from the part lying anterior to it, which has the histological characters of the piriform cortex (p. 1051).

The tertiary olfactory neurones arise in the piriform area and in the amygdaloid body. Many of the efferents from the two former pass into the hippocampal formation.

(4) The **hippocampal formation** is formed along the fringe of the pallium on the medial aspect of the hemisphere. It comprises (a) the *indusium griseum*, (b) the *longitudinal striae* of the corpus callosum, (c) the *dentate gyrus*, and (d) the *hippocampus*.

The hippocampal formation is laid down in the embryo on the medial wall of the hemisphere, forming an arch immediately outside the arch of the chorioid fissure (p. 139). The anterior or upper part of the arch is invaded by the corpus callosum, and the great size of this structure in the human brain reduces the corresponding portion of the hippocampal formation to the mere vestige which is represented by the *indusium griseum* on the surface of the corpus callosum (fig. 882) and the associated longitudinal striae. The posterior or lower part of the arch is carried downwards and forwards by the growth of the temporal lobe and so is not affected by the development of the corpus callosum. The *hippocampal sulcus* develops in this part of the hippocampal formation, outside the chorioid fissure, and the strip of cortex which lies between the two forms the dentate gyrus. The cortex at the bottom of the sulcus proliferates rapidly and bulges laterally into the cavity of the inferior horn of the ventricle, constituting the hippocampus (fig. 901).

(a) The *indusium griseum* is the thin sheet of grey matter which covers the upper surface of the corpus callosum and is continuous on each side, round the bottom of the callosal sulcus, with the cortex of the gyrus cinguli. It is continuous behind with the *gyrus fasciolaris (splenial gyrus)*, a delicate layer of grey matter which is in continuity with the posterior end of the dentate gyrus (fig. 895). In front it is continued round the genu and on to the inferior surface of the rostrum of the corpus callosum, to become continuous with the subcallosal area and the paraterminal gyrus.

(b) The *medial and lateral longitudinal striae* (fig. 894) are two ridges which extend forwards on the upper surface of the corpus callosum. The medial stria lies close to the median plane, but the lateral stria is placed under cover of the gyrus cinguli in the floor of the callosal sulcus. They consist of longitudinally running fibres, which sweep round the genu and over the rostrum to enter the paraterminal gyrus (*vide infra*). They represent the white substance of the vestigial *indusium griseum*.

(c) The *dentate gyrus* is a narrow, crenated strip of cortex which lies on the upper surface of the parahippocampal gyrus, under cover of the fimbria (fig. 883), from which

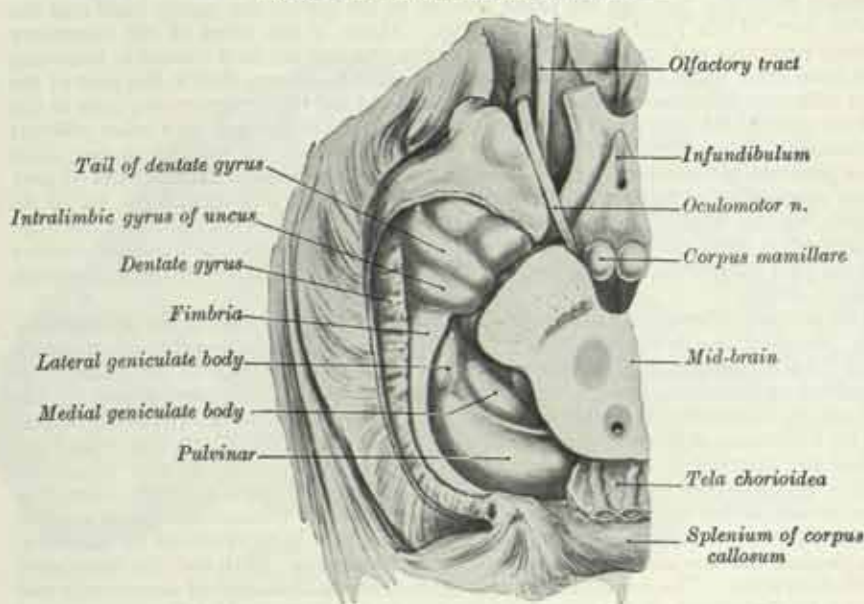
* W. F. Allen, *Am. J. Physiol.*, **128**, 1940, and **132**, 1941.

† According to some authorities most of the fibres of the *stria terminalis* are afferent to the amygdaloid body.

it is separated by the fimbriodentate sulcus. The *hippocampal sulcus* intervenes between it and the parahippocampal gyrus, but except at its anterior end this sulcus is not constantly present in the adult human brain. Posteriorly the dentate gyrus is prolonged on to the under surface of the splenium of the corpus callosum as the delicate gyrus fasciolaris (fig. 895), which in turn becomes continuous with the indusium griseum. Anteriorly the dentate gyrus is continued into the notch of the uncus, and then makes a sharp bend medially across its inferior surface (fig. 883). This transverse portion is termed the *tail of the dentate gyrus*. Unlike the rest of the gyrus it is smooth and featureless, and it becomes lost on the medial aspect of the uncus.

(d) The *hippocampus* is a curved elevation, about 5 cm. long, which extends throughout the entire length of the floor of the inferior horn of the lateral ventricle (fig. 901). Its anterior or lower extremity is enlarged and presents two or three shallow grooves separated by digit-like ridges, which give it a paw-like appearance. On this account it is termed the *pes hippocampi*. The elevation itself is usually described as being produced by the hippocampal sulcus, but, according to Elliot Smith, this is not actually the case, and the elevation owes its presence to the rapid

FIG. 883.—A dissection of the inferior surface of the brain to display the uncus, the dentate gyrus and the fimbria.



proliferation of the cells of the hippocampal formation in this situation. The ventricular surface of the hippocampus is covered by a layer of white fibres which constitutes the *alveus*, but the great bulk of the elevation is made up of grey matter. Posteriorly the hippocampus, like the dentate gyrus, becomes continuous with the gyrus fasciolaris at the splenium of the corpus callosum.

It should be stated that a wide range of experimental work carried out in recent years has produced no evidence to confirm the long established concept that the hippocampus and its efferent pathway, the fornix, are predominantly associated with olfactory sensibility. The discovery that the anterior nucleus of the thalamus, in which the mamillo-thalamic tract ends, projects on to the whole extent of the gyrus cinguli (p. 1002) drew attention to the apparently anomalous relation to the cortex of olfactory sensibility as compared with visual and other forms of sensibility.* Later, it was shown that dogs, trained to react with conditioned reflexes to odours of different kinds, continued to respond after bilateral destruction of the hippocampus but failed to do so after ablation of the piriform area.† As a result of these and other investigations,‡ it is now generally held that the hippocampus, and therefore the fornix, are not predominantly associated with olfactory impressions, and most authorities are of opinion that the hippocampus is mainly concerned with visceral and other autonomic

* W. E. Le Gros Clark and R. H. Boggon, *J. Anat.*, Lond., **67**, 1933, and *Brain*, **56**, 1933.

† W. F. Allen, *Am. J. Physiol.*, **128**, 1940, and **132**, 1941.

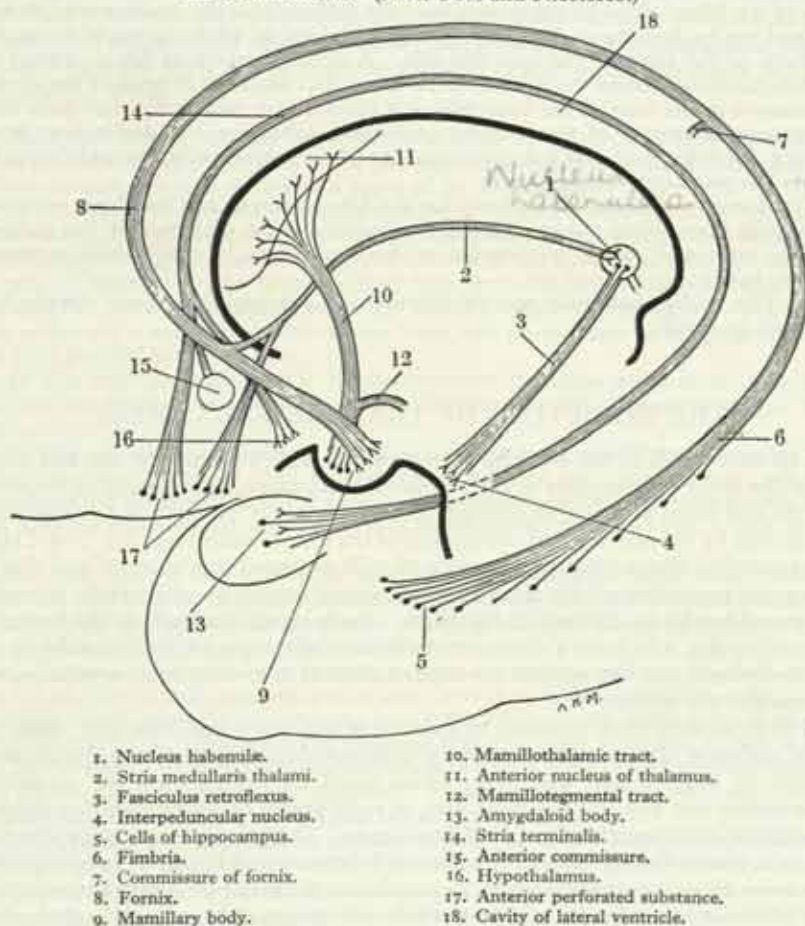
‡ A. Brodal, *Brain*, **70**, 1947, and W. K. Smith, *J. Neurophysiol.*, **8**, 1945.

activities. This view may be correlated with the fact that the hippocampus, both as regards its actual size and its size relative to that of the olfactory bulb, is greater in the human brain than it is in macrosmatic mammals.

(5) The *paraterminal gyrus* is the strip of the cortex which lies immediately in front of the lamina terminalis (fig. 870). Anteriorly it is limited by the posterior parolfactory sulcus, and superiorly it becomes continuous with the indusium griseum on the inferior surface of the rostrum of the corpus callosum. Inferiorly it is connected to the piriform area by a white band, termed the *diagonal band*, which runs laterally and backwards across the posterior part of the anterior perforated substance (fig. 864). The significance of the paraterminal gyrus in the rhinencephalon has not yet been determined.

(6) The *fornix* is the efferent pathway from the cells of the hippocampus conveying fibres to the mamillary body and the habenular nucleus. The fibres of the cells of the hippocampus pass to its ventricular surface where they form a layer of white

FIG. 884.—A scheme to show the connexions of the fornix, the stria terminalis and the tenia fornicis. (After Foix and Nicosesco.)



matter, termed the *alveus*. The fibres of the alveus converge on the medial border of the hippocampus to form the *fimbria*, a flattened band of white fibres which lies above the dentate gyrus and immediately below the lower part of the chorioidal fissure. The disposition of the fimbria is variable. It may project above the dentate gyrus, with a free medial edge, taenia fornicis, and a lateral border which merges into the alveus, or its free border may be twisted over towards the lateral side, uncovering the dentate gyrus (fig. 895). Anteriorly, the fimbria passes into the hook of the uncus (fig. 883). Traced backwards on the floor of the inferior horn of the ventricle, it ascends below the splenium and bends forwards above the thalamus, forming the *crus of the fornix*. The two crura are closely applied to the under surface of the corpus callosum and are connected to each other by a number of transverse fibres which pass between the hippocampal formations of the two hemispheres and form the *commissure of the fornix*.

(*hippocampal commissure*). This commissure presents the appearance of a thin, triangular lamina. Between it and the corpus callosum a horizontal cleft (the so-called *ventricle of the fornix*) is sometimes found.

Anteriorly the two crura come together in the median plane and constitute the *body of the fornix*, which is really a symmetrically disposed bilateral structure. The body of the fornix lies above the tela chorioidea and the ependymal roof of the third ventricle (fig. 909) and is attached above to the under surface of the corpus callosum and, more anteriorly, to the lower borders of the laminae of the septum pellucidum. Laterally the body of the fornix overlies the medial part of the upper surface of the thalamus (p. 1000) and the chorioid fissure is placed below its free, lateral edge. Through this fissure the chorioid plexus in the lateral margin of the tela chorioidea thrusts its way into the body of the lateral ventricle (fig. 909).

Above the interventricular foramen the body of the fornix separates into two *columns (anterior)*, which bend downwards and backwards, forming the anterior boundary of the interventricular foramen and passing behind the anterior commissure. As they descend, each sinks into the anterior part of the corresponding lateral wall of the third ventricle and reaches the corpus mamillare, in which it terminates (p. 1010). Some of the fibres of the fornix system leave the column near the interventricular foramen and run backwards, as the *stria medullaris thalami* (p. 1008), to reach the nucleus habenulae of the same or the opposite side. A slender bundle of fibres, named the *olfactory fasciculus*, leaves the column of the fornix and descends in front of the anterior commissure to the base of the brain where it divides into two parts; one runs along the anterior boundary of the anterior perforated substance—its destination is unknown; the other joins the indusium griseum of the corpus callosum and through it reaches the parahippocampal gyrus.

The fornix is the efferent pathway for the hippocampus, and its fibres, relayed in the corpora mamillaria, pass to the anterior nucleus of the thalamus by the mamillo-thalamic tract and to the tegmentum of the brain-stem by the mamillotegmental tract (p. 1010).

(7) The *nucleus habenulae* and its afferent and efferent fibres have already been described (p. 1008).

THE STRUCTURE OF THE CEREBRAL CORTEX

The nerve-cells of the cerebral cortex show a wide variation in size and shape, and in the mode of behaviour of their dendrites and axons. In all parts of the cortex they are laid down in strata, an arrangement which is very constant and is apparently determined by the number and complexity of the fibre connexions. Le Gros Clark * points out that fibres obtain easy access to cells arranged in a stratum and that for this reason expansion of the laminar arrangement occurs by an increase in surface extent and not by an increase in thickness. Such expansion leads to the formation of convolutions, which are a characteristic feature of the cortex in the cerebrum and the cerebellum, and this enables the expanded areas to remain in close relation with the vascular pia mater.

The transition from stratum to stratum is not sharp and clear-cut, and, as a result, different observers have adopted different descriptions of the stratification. It must be remembered that many fibres reach the cortex from the underlying white matter and run, for the most part, at right angles to the surface, breaking up the cellular constituents into parallel columns. Others, however, alter direction after penetrating the cortex and, together with intracortical fibres, form two sheets—or in some situations three—which lie parallel to the surface. The most superficial layer of the cortex consists of fibres which run tangentially. In the substance of the cortex there may be two sheets of fibres parallel to those in the superficial or molecular layer. They appear in sections of the cortex as narrow bands, termed the *outer and inner bands of Baillarger*; they vary in thickness in different cortical areas and consist, to a large extent, of intracortical arcuate fibres. In the visuosensory cortex, the outer band forms a strip which is broad enough to be recognised readily by the naked eye and is termed the *visual stria*. It appears as a white streak in the middle of the grey matter on sections of the visuosensory cortex (fig. 905) and it is so characteristic a feature that this part of the cortex is named the *striate area*. In many regions the inner band of Baillarger is completely obscured and it may be entirely absent.

The depth of the cortex is always greater on the exposed surfaces of the gyri

* *The Tissues of the Body*, Oxford, 3rd edition, 1952.

than it is in the depths of the sulci, and varies from 4 mm. in the precentral gyrus to 1.25 mm. in the occipital lobe.

In the human foetus at the sixth month three layers can be made out in the cortex, viz.—a superficial or *molecular layer*, consisting mainly of tangential fibres, an intermediate or *granular layer* of cells, and a deep or *infragranular layer* of cells. This three-layered arrangement is typical of the archipallium, and is found in the adult human brain in the hippocampal formation. The granular layer constitutes the receiving mechanism, and the infragranular layer the transmitting mechanism. In the later months of foetal life the neopallium becomes further differentiated. The advent of additional association and commissural afferent fibres leads to a thickening and differentiation of the granular layer. It gives rise to an *outer granular layer*, which merges into a *pyramidal layer* of cells. Deep to the pyramidal layer there is a fourth layer, consisting of small stellate or granular cells, termed the *inner granular layer*. At the same time, the infragranular layer thickens and differentiates into a deeper, *polymorphous layer*, in which small fusiform cells predominate, and a more superficial *ganglionic layer*, in which the cells are more densely packed and giant pyramidal or stellate cells may be found. The growth of the infragranular layer is contemporaneous with the increase in number of the corticofugal and outgoing commissural fibres.

The adult cortex may therefore be considered as subdivided into six different strata, which differ in the depths of the various layers and in the number and character of their constituent cells in different parts of the hemisphere.

(1) The *molecular layer* consists of a stratum of medullated fibres which run parallel to the surface. It varies in its depth and in the density of the fibres which it contains. In its deeper part it contains the apical dendrites of the pyramidal cells, the axons of the cells of Martinotti, and fibres derived from the subjacent white substance of the hemisphere. In addition, it contains (a) small, irregularly-shaped nerve-cells with short axons and a variable number of dendrites, and (b) fusiform cells, lying with their long axes parallel to the surface.

(2) The *outer granular layer* is of approximately the same depth as the first layer. The cells are small, averaging 8μ to 10μ in diameter, having disproportionately large nuclei.

(3) The *pyramidal layer* shows a gradual increase in the size of its constituent cells as they are traced inwards from the surface. Its outer part presents few variations throughout the whole extent of the cortex. The constituent cells are typical pyramidal cells, and are more widely separated from one another than the cells in the second layer.

The inner part of the pyramidal layer shows considerable variations in different areas. Its cells have an average diameter of $25\text{--}30\mu$, and they show a marked increase in the number and size of the contained Nissl's granules. The deepest part of this layer is traversed by the *outer band of Baillarger*.

(4) The *inner granular layer* forms a narrower stratum, made up of small stellate cells, which vary in their number and in their density in different cortical areas. They average $8\text{--}10\mu$ in diameter; their axons are short and terminate in the same layer or in the pyramidal layer. It is generally accepted that this layer functions as the *receptor layer* for incoming projection (thalamo-cortical) fibres. Here the afferent axons terminate by forming dense net-like plexuses,* which enable each to discharge on the dendrites and cytons of a large number of the granule cells.

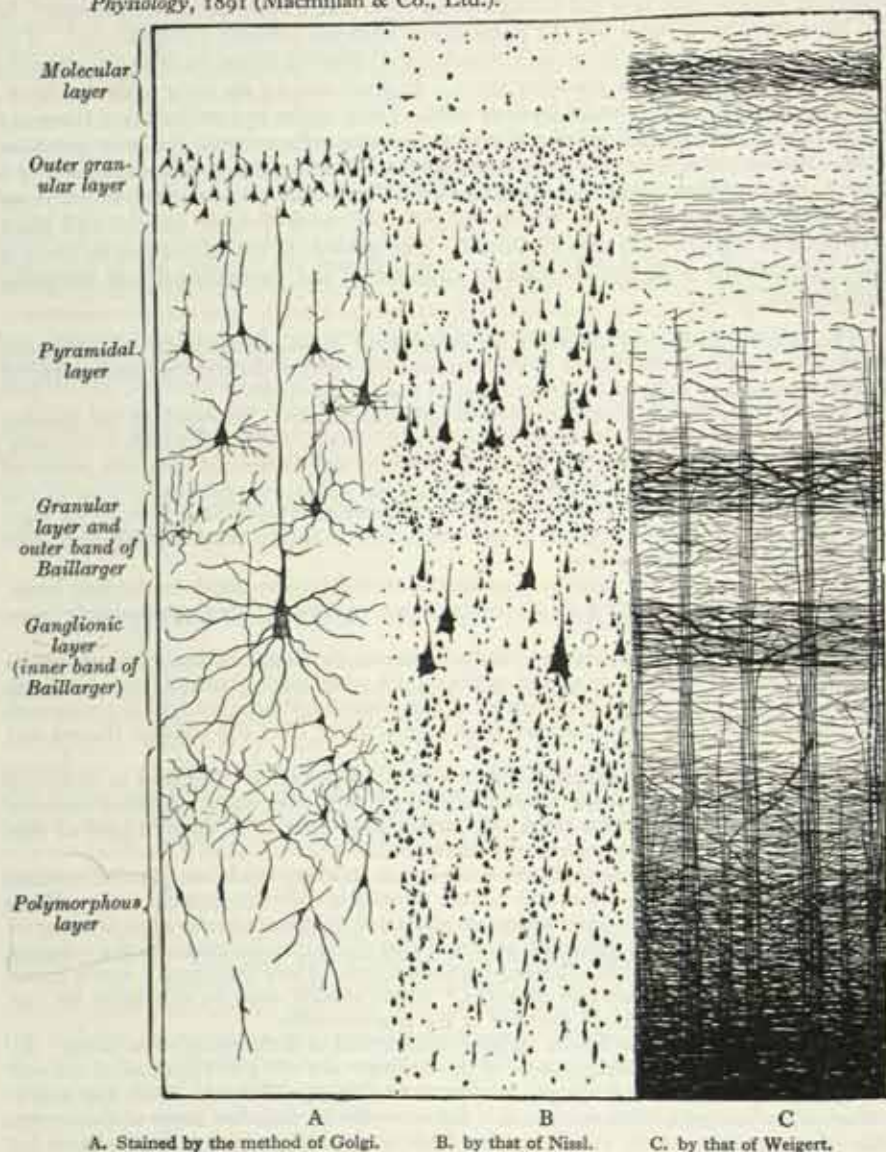
(5) The *ganglionic layer* shows striking differences in different cortical areas. In the motor area the characteristic cells of this stratum are the giant pyramidal cells of Betz (p. 1041), which vary from 35μ by 17μ to 60μ by 25μ (Bevan Lewis), but many smaller cells of varying form are found in the same layer. In other parts of the cortex large cells may be entirely absent, or the large pyramidal cells may be replaced by large stellate cells (visuosensory area, p. 1045). In certain situations the *inner band of Baillarger* is a recognisable feature in this stratum. The ganglionic layer functions as the *effector layer* of the cortex.

(6) The *polymorphous layer* is composed mainly of spindle-shaped or fusiform cells. These are subdivided into columns by sheets of radial fibres which traverse the polymorphous layer on their way to and from the more superficial layers of the cortex. Most of the axons of the polymorphous cells pass into the subjacent white matter, while their dendrites pass towards the surface but do not reach the molecular layer. The cells of Martinotti are found in this layer, as well as in the superimposed layers. They are pyramidal in shape, but their bases are directed towards the surface. Their dendrites are short and their axons pass into the molecular layer, where they form an

* Lorente de Nò, *Trab. Lab. Invest. biol. Univ. Madrid*, 20, 1922, and *J. Psychol. Neurol.*, (Lpz.), 45, 1934.

extensive horizontal arborisation. The cells of Martinotti are most numerous in the piriform area. The incoming and outgoing radial fibres vary in density with the fibre wealth of the individual area. They include the efferent axons of the cells of the ganglionic and of the polymorphous layers and the afferent projection, association and

FIG. 885.—A diagram showing the layers of cells and fibres in the grey matter of the cortex of the human cerebral hemisphere, according to the histological methods of Golgi, Nissl and Weigert. After Brodmann; from Luciani's *Physiology*, 1891 (Macmillan & Co., Ltd.).



commissural fibres together with the axons of the cells of Martinotti. In addition, numerous horizontal fibres intersect the radial fibres. They are derived from (a) the branching axons of Golgi cells, type II; (b) collaterals of the axons of the large pyramidal and polymorphous cells and of the cells of Martinotti; and (c) the collaterals of the incoming fibres.

The cells which constitute the grey matter of the cortex show great variation in their size and shape and in the mode of behaviour of their axons and dendrites. The pyramidal cells, the cells of Martinotti, and the Golgi cells, type II, constitute a very large proportion of the total. (a) The pyramidal cells, irrespective of their size and their position, send basal dendrites into the surrounding area, and apical dendrites towards the surface, where they terminate by arborising in the molecular layer. Their axons arise from the base of the cell or from one of the basal dendrites and run cen-

trally into the deeper layers or into the white matter. They give off collaterals, many of which ascend to the more superficial strata. The small pyramidal cells are very susceptible to the effects of local anæmia. (b) The cells of Martinotti may be pyramidal, ovoid or fusiform in shape. They are characterised by the course of their axons, which ascend to reach the molecular layer and there divide into tangential branches. These cells are found in all the layers of the cortex, but are largest and most numerous in the polymorphous layer. Many of the afferent fibres to the cortex terminate by arborising with the dendrites of the cells of Martinotti, and the impulses which they convey are carried by the axons of the same cells to the molecular layer where they establish contact with the dendrites of the pyramidal cells. (c) The Golgi cells, type II, vary in size and in position. They are characterised by the shortness of their axons, which never leave the grey substance although they may pass from one layer to another. They establish connexions between cells in the same layer and also between cells in different layers. The great profusion of these short axon cells is a distinguishing feature of the human cortex. They provide chains of neurones which not only synapse with incoming axons but also with each other in series and frequently all of them with a dendrite or the cell-body of the same effector neurone. Further, an ascending collateral from that neurone synapses with the units of the chain (fig. 886). In this way it is ensured that the original incoming nerve impulse is capable of starting a series of impulses which bombard the effector neurone, not as a single volley but at very short intervals, and this bombardment facilitates transmission of the impulse through the effector and is immediately repeated through the synapses of its collaterals.

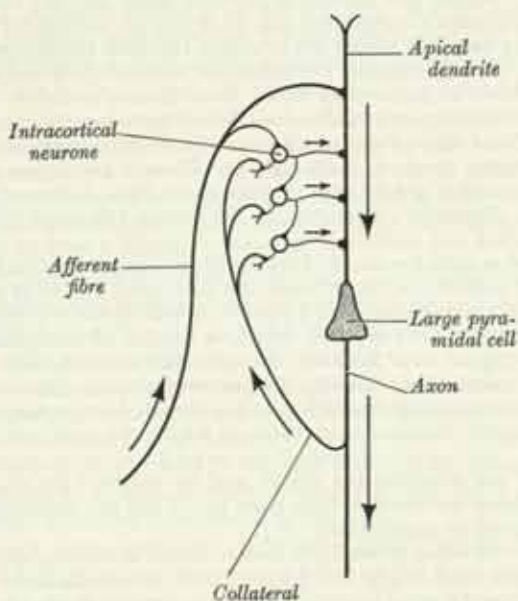
Many of these chains are not restricted to short axon cells but may include cells with longer axons which synapse with cells in other layers. The chains, therefore, may be extensive and offer a multiplicity of pathways leading to the effectors. In this way the limitations imposed by the character of the nerve impulse and its mode of propagation (pp. 917, 919) are compensated for by an arrangement which enables a single incoming impulse to 'touch off' a large number of different pathways towards the effector cells. It is conceivable that only a proportion of these pathways is passable at any one time and that those utilised are determined by a pre-existing pattern (p. 1042) which facilitates their passage.

It has been estimated that the brain contains at least ten thousand million neurones, most of which are linked up in circuits of greater or lesser complexity by numerous alternative pathways. The vast profusion of these neuronal connexions opens up unlimited possibilities and indeed baffles description.

The researches of Brodmann,* Economo,† Lorente de Nò‡ and others into cortical structure, the embryological investigations of Flechsig and the experimental work of Sherrington and many others, have shown that the cortex of the cerebral hemispheres can be mapped out into a number of areas which differ from one another (a) in the details of their structure, (b) in the period of myelination of their efferent fibres, and (c) in their functional significance.

Of the five fundamental types which Economo recognises in the cortical structure of the neopallium, the agranular and the granular varieties are the most dis-

FIG. 886.—A diagram to illustrate the part played by some of the small intracortical neurones in reinforcing afferent impulses. (After Lorente de Nò.)



* K. Brodmann, *Vergleichende Localisationslehre der Grosshirnrinde in ihren Prinzipien dargestellt auf Grund der Zellenbaues*, Leipzig. 1909.

† C. von Economo, *The Cytoarchitectonics of the Human Cerebral Cortex*, Oxford 1929.

‡ Lorente de Nò, *loc. cit.*, *Am. J. Physiol.*, 1935-1938, and *J. Neurophysiol.*, 1, 1938.

tinctive, as they represent the extremes of the variations which occur. The *agranular type* is marked by the almost complete absence of the granular cells, which are replaced by small pyramidal elements. It is found in the motor and premotor areas (4 and 6), including the adjoining areas 8 and 44 (fig. 889) and also in the anterior part of the gyrus cinguli (area 24). The *granular type* is marked by the depth and density of the granular layers, by the reduction in number of the pyramidal elements and by the diminution in the total depth of the cortex. It is found in the basically sensory areas, viz. the somesthetic (areas 3, 1 and 2), the visuosensory or striate (area 17) and the audiosensory (areas 41 and 42).

Simplified maps of the more important cortical areas, with Brodmann's numbering, are included as figs. 889 and 891. Owing to the increasing use of these distinguishing numbers by neurologists and physiologists they are included in this edition, in brackets as a rule. The reader should note that the areas are not numbered in serial order and that the numbers themselves have no significance beyond their value as labels and abbreviations.

METHODS OF INVESTIGATION

Before the individual cortical areas and the functions with which they are predominantly concerned can be described intelligibly, brief reference must be made to the methods which are available for their investigation.

Much valuable evidence has accrued from the study of *pathological or traumatic lesions* in patients suffering from disease or injury of the brain. Unfortunately the precise extent of the areas affected can rarely be determined with certainty and, to be of real value, these results must be checked in the light of evidence obtained by experimental methods, although the Marchi and other special methods of staining have proved of great value in tracing out fibre pathways in postmortem material.

Electrical stimulation of the cortex has been utilised for many years and, in the motor and premotor areas, has provided a mass of information which has increased in value with the steady improvement of apparatus and with the refinement of technique. In recent years strychnine has been used as a local stimulating agent, a square mm. of filter paper, soaked in a 3 per cent. solution of the sulphate being applied to the exposed cortex. This method, which is termed *physiological neuronography*, acts through the synapses and 'fires off' the neurones over which it is applied in their normal direction of conduction. During the process the electrical condition of other cortical areas (and of subcortical nuclei) may be recorded and changes of electrical potential are constantly obtained from those to which the strychninised area projects.

Destruction of parts of the cortex by ablation, thermo-coagulation or by the removal of the covering pia mater and its vessels have been employed and the subsequent effects on function have been noted and the resulting degenerated pathways have been traced in many cases.

Incisions through the cortex, aimed at cutting specified groups of subcortical fibres, have been employed experimentally in animals and in the surgical procedure originally termed *frontal leucotomy* and now usually labelled *prefrontal lobotomy*. This operation is now often undertaken in cases of profound mental disturbance which have failed to respond to other therapeutic measures, with the object of dividing the fibres which project on to the frontal area of the cortex (p. 1043).

It should be noted that all these methods necessitate some extraneous interference and the information they provide may often be suspect on that account. The introduction of the *electro-encephalograph* has, however, provided a means of examination of the electrical condition of different areas of the cortex under normal conditions, at rest, in activity and during sleep. As the instrument can be utilised for the direct examination of the cortex, not only in experimental animals but also in man during the course of surgical operations on the brain, the results of indirect examination through the skull and the tissues of the scalp can be assessed and the necessary allowances made. Electro-encephalography has shown that rhythmic changes of electrical potential can be obtained constantly from all accessible areas in normal subjects and that they undergo varying modifications during conscious activity. It can therefore be inferred that the brain is normally in a state of almost constant activity even though only a small part—if any—of this activity reaches consciousness. Some authorities believe that this unconscious activity plays an important part in maintaining open the countless pathways and circuits and the neurones concerned facilitated. Thus, when the need arises, appropriate conscious responses can be aroused with minimal delay.

In the resting condition the parieto-occipito-temporal region is dominated by the *alpha rhythm*, which lies within the range 8-13 cycles per second, but when the attention of the subject is aroused, the rhythm changes to one of higher frequency. On the other hand, the frontal part of the cortex is normally dominated by the *beta*

rhythm, 14-25 c/s, and this persists both at rest and during attention. Abnormal rhythms occur under pathological conditions, e.g. epilepsy, brain tumours, etc., and provide information which has a real clinical value. The physiological processes which underlie the electrical activity of the cortex are still the subject of considerable controversy and hitherto the results obtained by electro-encephalograms of normal, healthy subjects have added little to our knowledge of brain function. It must be stressed that there appears to be no obvious inter-relation between the structure of the cortex in any given area and the character of its electro-encephalogram.

THE CORTICAL AREAS

The **precentral area** includes the precentral gyrus and the posterior portions of the superior, middle and inferior frontal gyri. The whole of this area is characterised by the almost complete absence of the granular layer. It shows a wealth of intracortical fibres and the molecular layer is unusually dense.

The precentral area is divisible into anterior and posterior parts (fig. 888). The posterior part, which comprises the whole of the precentral gyrus and the adjoining part of the paracentral lobule constitutes the *motor area* (area 4) of the cortex. The anterior part, which comprises the posterior portions of the superior, middle and inferior frontal gyri, is termed the *premotor area* (area 6). Experimental evidence* has shown that the motor area plays a predominant part in controlling the volitional movements of the opposite half of the body and that the paracentral lobule (which is also concerned with the cortical control of micturition and defaecation), together with the upper part of the precentral gyrus control the movements of the lower limb. Below, and in the order given, are found the centres for the trunk, upper limb, face (upper part), larynx, lips, jaw, tongue and pharynx. The clinical evidence and the evidence obtained by electrical stimulation indicate that these centres are not sharply separated from one another but overlap considerably.

In lower mammals the motor centres are disposed as a broad, anteroposterior strip adjoining the longitudinal fissure, the head area occupying the most anterior position and the lower limb the most posterior but in the higher forms the great expansion of the frontal region extends backwards between the fissure and the areas for the head, forelimb and trunk, which therefore come to lie below the hindlimb area instead of in front of it.† Although, with more delicate stimulators and more refined methods, some observers have succeeded in obtaining contractions of single muscles and even of groups of fibres in a large muscle, it remains true that the prime function of the motor area is to initiate and organise purposive movements, for *it is movements and not individual muscles which are represented in the cortex.*

Large pyramidal cells are present in the ganglionic layer throughout the whole of the motor area. They vary in height from 30μ to 120μ , and in breadth from 15μ to 60μ , the largest being termed the *giant pyramidal cells of Betz*. These occur in small groups and are much more numerous in the paracentral lobule and the upper part of the precentral gyrus than in the middle part of the gyrus, where they are found only in its posterior half. In the lower third of the gyrus, Betz cells are very few in number and are restricted to the anterior wall of the central sulcus. Betz cells, the number of which has been estimated at 30,000,‡ must not be regarded as specific cells but rather as the largest members of a particular group of large pyramidal cells, all of which send their axons into the great corticospinal and corticonuclear (motor) tracts, a pathway that contains between 750,000 and 1,000,000 fibres.†

The *premotor area* resembles the motor area in structure, except for the absence of the very large pyramidal cells from the ganglionic layer. The two areas stand in very intimate relationship to each other from the functional standpoint, but the precise relationship is by no means easy to define. Some idea may be conveyed by the statement that, whereas the motor area (4) plays a predominant part in connexion with the production of voluntary movements, the premotor area (6) appears to be associated with the control of the orderly series of movements which constitute acts. The young child experiences no difficulty in performing individual

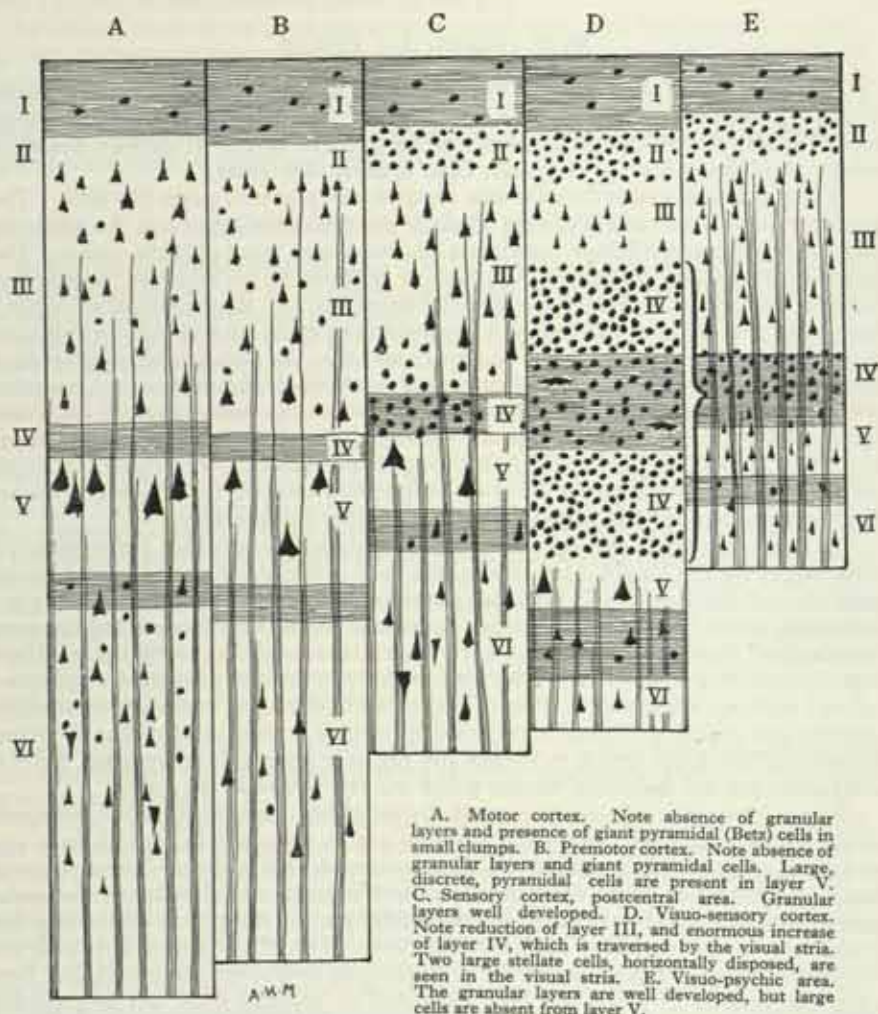
* A. S. Leyton, and C. S. Sherrington, *Quar. J. Exper. Physiol.*, **11**, 1917; and W. Penfield, and E. Boldrey, *Brain*, **60**, 1937.

† A. A. Abbie, *Essays in Biology*, Burkitt Memorial Volume, 1948.

‡ A. Lassek, *Arch. Neurol., Psychiat.*, **44**, 1940, and **47**, 1942.

movements, but has to learn by repeated efforts how to carry out even the simplest acts, such as putting on or buttoning a coat. Every act calls for the performance of a complicated series of movements which must be carried out in their proper sequence and to their proper extent, and forms a sort of pattern, which is capable of registration. All skilled acts must be learned by repeated efforts, and their mastery means that their pattern has been impressed on the nerve cells and the

FIG. 887.—A diagram showing five different types of cerebral cortex.



The relative depths of the individual layers, and the relative depths of the whole cortex are approximately accurate.

pathways concerned in the precentral area and also, conceivably, in other areas of the cortex, in the cerebellum and the various parts of the extrapyramidal system (p. 1076).

The condition of *apraxia*, which is normal in the young child, may be met with in later life as a manifestation of a pathological condition indicating a cortical or subcortical lesion in the neighbourhood of *area 6*. Such patients are able to carry out individual movements without difficulty, but they cannot perform coordinated movements, such as lighting a pipe.

Immediately in front of *area 6* there is a less extensive *area (8)*, which is very similar to it in structure but shows transitional changes anteriorly as it passes over into the *frontal area*. Those parts of *areas 6* and *8* which occupy the posterior portion of the middle frontal gyrus are concerned with the movements of the eyes

and constitute the *frontal eye field*. Electrical stimulation of parts of this field causes conjugate deviation of the eyes to the opposite side and other ocular movements (see also p. 1046).

Finally, the whole precentral area is closely associated with the cerebellar hemisphere of the opposite side. On the one hand it contributes most of the fibres to the cerebro-ponti-cerebellar pathway (p. 963); on the other, it receives the projection of the cerebello-thalamo-cortical fibres and extensive lesions of the area are associated with degenerative changes in the contralateral dentate nucleus.*

Broca's area (44 and 45, fig. 889) is a specially elaborated part of the premotor cortex and plays an essential rôle in connexion with the laryngeal, lingual and other movements employed in speech. It is often described as the *motor speech centre*.

The *frontal area* extends from the premotor area to the frontal pole and includes the medial frontal gyrus in front of *area 8* (fig. 891). Some authorities consider, on physiological grounds, that it should include not only the orbital gyri but also the anterior part of the gyrus cinguli, dealt with on pp. 1048, 1049.

Histologically this area differs from the adjoining precentral area in the re-appearance of the granular layers and in the diminution of the number of intra-cortical fibres. The ganglionic layer shows a corresponding reduction in the size and number of its constituent cells, and the polymorphous layer is considerably reduced in depth.

The frontal area receives *afferent fibres* from the medial nucleus of the thalamus, which appear to have a 'point-to-point' relationship, as well as others from the superior part of the lateral nucleus. It sends *efferent fibres* to the medial thalamic nucleus and also contributes fibres to the fronto-pontine pathway (p. 963). In addition, numerous connexions with the primary sensory areas through the long arcuate fasciculi (p. 1059) have been assumed but, hitherto, confirmation has been lacking, owing, in part at least, to technical difficulties.

Because of the absence of gross symptoms following many cases of injury and disease, the frontal area was long known as the *silent area* of the brain. It has been generally accepted that it analyses incoming impressions into those which arouse feelings of pleasure and well-being and those which are unpleasant or distasteful. It determines the personal reaction of the individual according to the alterations in feeling tone, modified or intensified, as the case may be, in the light of past experience, and is therefore responsible, in a general way, for behaviour and conduct. It is also concerned with attention and the power of mental concentration, and with emotional manifestations. These views receive considerable support from clinical evidence. Lesions of the frontal area, whether cortical or subcortical, commonly result in some alterations in the character of the patient—alterations which may be so slight as to be recognised only by his intimates, or may be so gross as to be obvious to any observer. The operation of *prefrontal lobotomy* has in many cases been efficacious in abolishing obsessional and other seriously disturbed mental states, and has also been performed when the operation of cordotomy (p. 944) has failed to relieve the constant distressing pain in some cases of inoperable cancer. In the latter cases the patients, when subsequently interrogated, have said that they still had the pain but that it no longer distressed them, and it may be that the section of the nerve fibres involved in the operation, had interfered with some of the pathways concerned in fixing attention and concentration.

The concept of the functional activities of the frontal area outlined above have recently been challenged † on more grounds than one. It is claimed that the importance of the frontal area has been exaggerated and the significance of its thalamic, and therefore hypothalamic, connexions has been underestimated. It is pointed out that the only arcuate fibres of the frontal area which have been unequivocally identified are those from the frontal eye field to *area 18*, while, on the other hand, a wealth of association fibres pass to and from the temporal and the parietal association areas. There is evidence, too, that the expansion of the latter areas in the process of evolution has equalled, and may even have exceeded the expansion of the frontal area, which has hitherto been accepted as a specially characteristic feature of the human brain. From the physiological standpoint it is suggested that the fronto-thalamo-hypothalamic connexions indicate that the real importance of

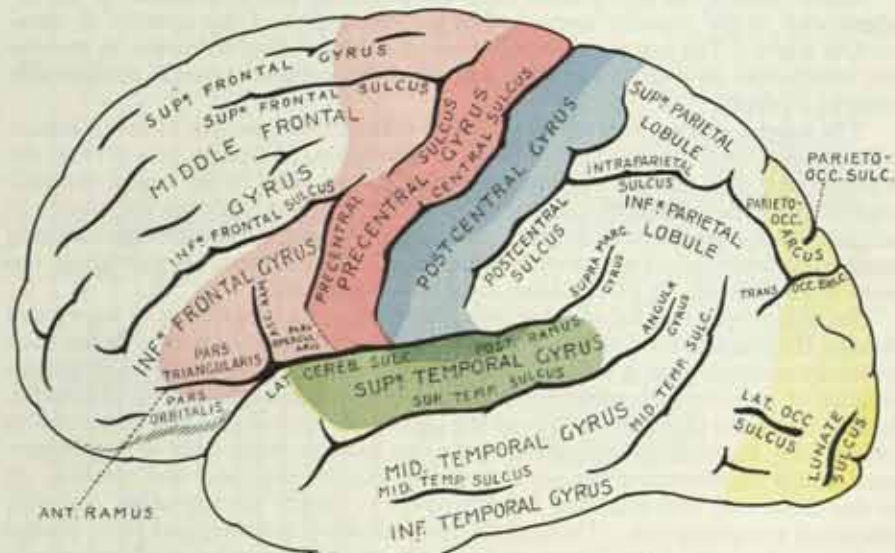
* G. E. Smyth, *Brain*, 64, 1941.

† W. E. Le Gros Clark, *Lancet*, I, 1948; and W. Ritchie Russell, *Lancet*, I, 1948.

the frontal area lies in the obvious inference that it provides a cortical motor area for the autonomic system.*

The **postcentral area** occupies all but the lowest part of the postcentral gyrus and is continued over the superomedial border into the adjoining part of the paracentral lobule. It is divisible into anterior and posterior parts, which show certain differences in structure and play related, though distinct, parts in the reception and appreciation of somesthetic impressions. The anterior part (*area 3*, fig. 883) is characterised by the number of characteristic cells in the pyramidal layer, by the density of the granular layers and by the breadth of the outer band of Baillarger. The largest cells are found in the ganglionic layer, but they are smaller than the giant cells of Betz and they occur discretely instead of in small clusters. In the posterior part (*areas 1 and 2*) the large pyramidal cells are reduced both in size and number, and the inner granular layer, though rather wider, is not so densely packed with cells.

FIG. 888.—The areas of localisation on the lateral surface of the left cerebral hemisphere.



Motor area in red. Somesthetic area in blue. Auditory area in green. Visual area in yellow. Premotor area in pink. The psychic portions of the somesthetic, auditory and visual areas are in lighter tints.

The postcentral area receives afferent fibres from the thalamus, which represent the relays of the somesthetic fibres of the spinal medulla and brain-stem. Impulses of both exteroceptive and proprioceptive sensibilities stream into the postcentral area and receive their full recognition in consciousness. The anterior part of the area may be regarded as the actual receiving area for all varieties of somesthetic sensibility, and the posterior part of the area relates them with past experience and so renders possible their evaluation and discrimination. It is therefore responsible for the tactile element in stereognosis, i.e. the recognition of shape and texture, in its widest sense, without the aid of vision.

The topical localisation in the postcentral area corresponds, generally, to that in the motor area.† The genitalia and anal region and the lower limb below the knee are represented in the paracentral lobule. The knee and thigh occupy the

* J. F. Fulton, *Functional Localisation in the Frontal Lobes and Cerebellum*, Oxford, 1949.

† C. N. Woolsey, W. H. Marshall and P. Bard, *Johns Hopk. Hosp. Bull.*, 70, 1942. These observers, by 'leading off' from different parts of the somesthetic cortex of monkeys while applying tactile and other stimuli to specific cutaneous areas, found that the cortical sensory representation was apparently segmental, but with a curious break in the continuity. The coccygeal, sacral and lowest lumbar segments were identified in the paracentral lobule and the remaining lumbar and the thoracic segments in the postcentral gyrus, but the first thoracic segment was succeeded by the second cervical segment, and this by the other cervical segments in numerical order, so that the trigeminal area adjoined the eighth cervical segment.

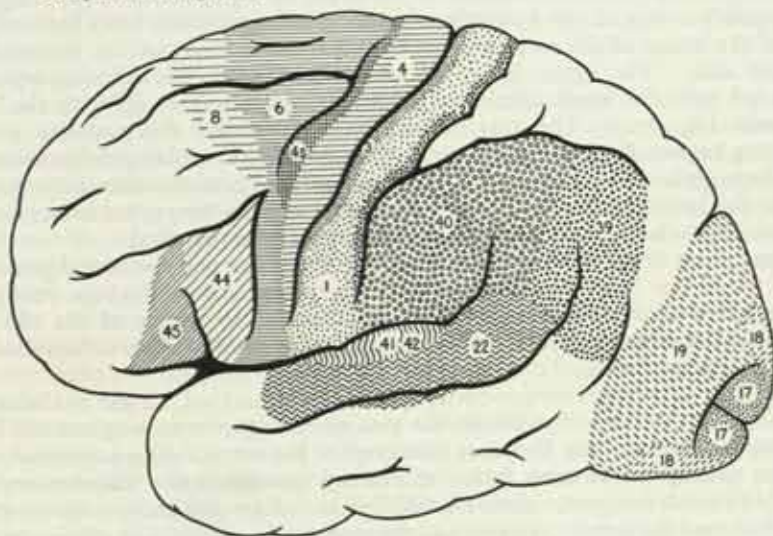
superior part of the postcentral gyrus and are succeeded by the trunk, upper limb, face, mouth, lips and tongue, *including taste*, in that order. The area in which the hand, fingers and thumb are represented is, as might have been anticipated, disproportionately large.

The **visual** area of the cortex includes the greater part of the occipital lobe, and is subdivided into the *visuosensory* or *striate* area and the *visuopsychic* area.

FIG. 889.—A diagram of the lateral aspect of the left cerebral hemisphere, showing some of the cortical areas. (After Brodmann.)

Observe that area 18 is buried in the lunate sulcus and that, on this account, areas 17 and 19 are contiguous along the line of the sulcus.

Compare with fig. 888.



Note.—The numerals are not used in serial order, but they and the different patterns of shading indicate differences in microscopical structure.

Areas 4 and 48= motor area: areas 6 and 8= premotor area: area 3= somesthetic area: areas 1 and 2= psycho-somesthetic area: areas 44 and 45= motor speech area: areas 41 and 42= auditory area: area 22= auditory speech area: areas 39 and 40= sensory speech areas: area 17= striate area: area 18= parastriate area: area 19= peristriate area.

The **visuosensory area** (area 17) occupies the walls of the posterior part of the calcarine sulcus and extends on to the surface of the cuneus above and the lingual gyrus below. Posteriorly it may not extend beyond the occipital pole; when it does extend on to the convex surface it is limited by the lunate sulcus in front, and by the polar sulci above and below. Anteriorly the visuosensory area occupies the floor of the calcarine sulcus and the adjoining part of the lingual gyrus (fig. 891). The whole of this area is characterised by the conspicuous *visual stria*, which is quite obvious to the naked eye (fig. 905), and by the shallowness of the cortex. Over the anterior part of the area the stria is broad and a darker strip lies on its inner side. In the polar region and on the lateral aspect of the hemisphere, it becomes narrower and the accompanying dark band disappears. This change in the character of the stria corresponds to a difference in the retinal relationships of the striate area (*vide infra*). Histologically the visuosensory area presents four distinguishing features. (1) The deeper part of the pyramidal layer contains a few large stellate cells, which almost entirely replace the large pyramidal cells normally found in this position. They are horizontally placed and were regarded by Cajal as specific visual cells. (2) The outer band of Baillarger is broad and conspicuous, constituting the *visual stria* (Gennari). Although it contains many fibres from the optic radiation, it appears to be formed for the most part by intracortical connecting fibres. (3) The ganglionic layer contains the large, solitary cells of Meynert. These are pyramidal in shape, measuring about 30μ , and are arranged in a single, widely spaced, row. Their dendrites extend for a considerable distance, enabling the cell to collect impulses from an extensive area. Their axons, which are basal, pass directly into the subjacent grey matter, traverse the optic radiation and end in the superior colliculus, or the adjoining part of the mid-brain. (4) The outer and, more especially, the

inner granular layers are very conspicuous and the small cells which they contain are closely packed together. The enormous number of these diminutive elements is a characteristic feature and will be appreciated more fully when it is stated that the striate area contains approximately one-tenth of the total number of the cells in the cerebral cortex. The inner granular layer appears to be duplicated. It receives the terminals of the fibres of the optic radiation, each of which ends in relation to a number of granule cells.

The visuosensory area is the cortical receiving centre for visual impressions. Colour, size, form, motion, illumination and transparency are all recognised and appreciated in this area. The recognition and identification of objects, however, requires the co-operation of the adjoining visuopsychic area.

Owing to the partial decussation of the fibres of the optic nerve (p. 1015), the visuosensory cortex of one hemisphere receives its impressions from the temporal part of the retina of the same side and from the nasal part of the retina of the opposite side. The upper lip of the posterior part of the calcarine sulcus is associated with the upper quadrants indicated, and the lower lip with the lower quadrants (fig. 872). The area for the macula occupies the posterior portion extending backwards to the lunette, upwards to the superior polar and downwards to the inferior polar sulcus. As might have been inferred from the size of the macular area in the lateral geniculate body, the macular area in the cortex is much more extensive than the cortical area for the peripheral retina (fig. 872).

The 'point to point' relationship between the retina and the lateral geniculate body, which has been demonstrated by the experimental method (p. 1006), has received further confirmation by the determination, by means of the electrical method of investigation,* of a 'point to point' relationship between the retina and the visuosensory cortex.

So far as its efferent cortico-cortical fibres are concerned, all the available evidence appears to show that the striate area gives origin to no long arcuate fibres and that its short arcuate fibres are restricted to the surrounding parastriate area.

The **visuopsychic area** (*areas 18 and 19*) surrounds the visuosensory area except in its anterior part. *Area 18*, which is in surface continuity with the striate area, is termed the *parastriate area* and, on its outer border, it is in continuity with *area 19*, which is termed the *peristriate area* (figs. 889 and 891). The cortex is rather shallower than the cortex of the visuosensory area and is characterised by the breadth of the outer band of Baillarger, which is just as broad as it is in the visuosensory area, though its edges are not quite so sharp.

This area is responsible for the correlation of visual impressions and their association with past experience, leading to the identification and recognition of objects and also to the determination of distance and the proper orientation of objects in space.

By means of physiological neuronography (p. 1040) it has been shown that *area 18* 'fires' the adjoining parts of *areas 17 and 19* and also the contralateral *area 18*.† *Area 19*, on the other hand, 'fires' only *area 32* (and, according to some authorities, *area 31*) on the medial aspect of the hemisphere (fig. 891). On electrical stimulation it has been shown to contain an 'occipital eye field', which gives rise to conjugate deviation of the eyes to the contralateral side and to constriction of the pupil, through fibres which descend through the posterior part of the internal capsule to reach the nuclei of the cranial nerves concerned.‡ This descending pathway is regarded as part of the cortically integrated reflex arc concerned with the optical reflexes of accommodation and fixation (see also p. 1256). Unlike the 'frontal eye field' (p. 1043) the occipital eye field does not participate in the purely voluntary movements of the eyes.

In addition, *area 18* receives long arcuate fibres from the region of the frontal eye field, and this is one of the few long arcuate fibre bundles, the connexions of which have been clearly established.

The **parietal area** is situated between the visual area behind and the post-central area in front, and constitutes one of the large association areas of the hemisphere. Histologically this area is characterised by the absence of large elements from the ganglionic and pyramidal layers and by the breadth of the inner band of Baillarger. The outer and inner granular layers are well developed.

* S. A. Talbot and W. H. Marshall, *Amer. J. Ophthalm.*, **24**, 1941.

† G. von Bonin, H. W. Garol and W. S. McCulloch, *Biol. Symposia*, **7**, 1942.

‡ R. W. Barris, W. R. Ingram and S. W. Ranson, *J. Comp. Neurol.*, **63**, 1936.

Owing to its position relative to the visual, somesthetic and auditory areas, the parietal area is advantageously situated for the purpose of correlating items of information obtained from these sensory areas and it is commonly believed that through the activities of this part of the brain accurate knowledge of objects and their significance is obtained and retained. The inflow of repeated sensory impressions—visual, tactile and proprioceptive—arising from frequent handling of an object, lays down a pattern which enables the object to be identified *without the aid of vision* and this is termed *stereognosis*. Cortical cells, similar to the one depicted in fig. 886, together with countless association fibres, play an important part in the establishment of this pattern and in the process of its establishment by repeated use the circuits concerned become facilitated so that the pattern itself can readily be evoked. Loss of stereognostic sense—'astereognosis'—is regarded as clinical evidence of a lesion affecting the parietal lobe, although the diagnosis of the probable position of the lesion within the lobe will in most cases depend on the other signs and symptoms exhibited by the patient.

Lesions of the inferior parietal lobule, especially those affecting the angular gyrus, interfere with the sensory speech pathways and usually manifest themselves by causing complete inability to understand the written or spoken word, despite the fact that vision and hearing are both normal. The connexions of the angular gyrus (area 39) with the pulvinar (p. 1003) may explain the inability of such patients to read, but the interconnexions between the three great sensory areas and their connexions with the motor and premotor areas are so numerous and complicated that they defy complete analysis.

The **auditory area** of the cortex is associated with the superior temporal gyrus and the transverse temporal gyri. Like the visual area, it can be subdivided into a sensory and a psychic part, the latter adjoining and to a large extent surrounding the former.

The *auditosensory area* (areas 40, 41) occupies the anterior transverse temporal gyrus, which lies in the floor of the posterior ramus of the lateral sulcus (fig. 878), and extends, for a short distance and over a limited area, on to the lateral surface of the superior temporal gyrus below and behind the lower end of the central sulcus. Histologically this area of the cortex is characterised by the arrangement of its cells in columns set at right angles to the surface, by the thickness of the outer and inner granular layers, and by the great number of fibres which are found throughout its whole depth.

Afferent fibres reach the auditosensory area from the medial geniculate body, after sweeping below the lentiform nucleus and forming the *acoustic radiation*. Recent investigations by the electrical method * indicate that there is a spatial correspondence between the cochlea and the auditosensory cortex. In the cat the apical turn of the cochlea, which is tuned to notes of low pitch, supplies the posteromedial part of the area, while the basal turn, which is tuned to notes of high pitch, supplies its anterolateral part. In the adjoining auditopsychic area, however, the apical turn is represented anteriorly and the basal turn posteriorly.†

In the auditosensory area auditory impressions reach consciousness as sounds, and their loudness, quality and pitch can be differentiated. The direction from which the sound comes and its character, whether rhythmical or arrhythmical, are also determined by this part of the cortex. The significance and the source of the sound, however, require the adjoining auditopsychic area for their elucidation.

Efferent fibres from areas 40 and 41 pass to the regions of the eye fields in the frontal (p. 1043) and occipital (p. 1046) lobes, and the corresponding areas of the two hemispheres are connected by fibres which traverse the corpus callosum.

The *auditopsychic area* (area 22) occupies the whole of the remainder of the superior temporal gyrus. Histologically it resembles the auditosensory cortex, but the granular layers are shallower and the pyramidal layer is deeper. In this area auditory impressions receive their interpretation and can be differentiated from one another, as regards their probable source and origin, by association with past experience.

The large *temporal area*, which includes the whole of the middle and inferior temporal gyri, is very similar to the auditopsychic area in its cortical structure. Lesions of this area are accompanied by a more or less marked disturbance of the auditopsychic functions. Although there is some evidence of the presence of

* J. C. R. Licklider and K. D. Kryter, *Fed. Proc. Amer. Soc. Exp. Biol.*, 1, 1942.

† C. N. Woolsey and E. M. Walzl, *Johns Hopk. Hosp. Bull.*, 71, 1942.

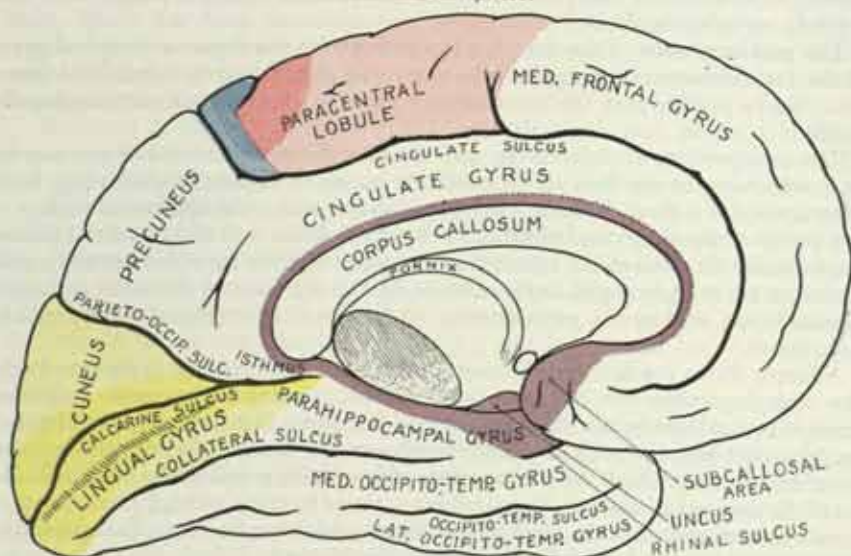
intercortical connexions with *area 19*, it must be confessed that our knowledge of the functional significance of this large part of the cortex is meagre.

The **insular area** comprises the whole of the insula. Histologically two types of cortex are recognisable. The structure of the cortex of the long gyrus shows many points of resemblance to that of the temporal area, whereas the cortex of the short gyri is more closely allied to the cortex of the parahippocampal gyrus. No afferent thalamic fibres have been demonstrated in connexion with this cortical area, but the results of electrical stimulation suggest its connexion with the alimentary tract* and may be correlated with its intimate topographical relationship to *area 13* (p. 1049).

The **cingulate area** comprises the whole extent of the gyrus cinguli, which, on the grounds of its structure, is divisible into three parts, *v.z.* *areas 24, 23* and *31*.

Area 24 (fig. 891) occupies approximately the anterior half of the gyrus and is characterised by the paucity of the cells in its granular layers. Afferent fibres are received from the anterior nucleus of the thalamus† and, in this way, it is linked with the hypothalamus. Its efferent fibres pass to the caudate nucleus and to the adjoining *areas 32* and *31*. When subjected to electrical stimulation it exercises a variable effect on the pulse rate and on blood pressure, depending on the intensity of stimulation, and produces other autonomic effects, according to the part stimulated. On this account it is regarded by some as an integral part of the frontal lobe.

FIG. 890.—The areas of localisation on the medial surface of the left cerebral hemisphere.



Motor area in red. Somesthetic area in blue. Visual area in yellow. Olfactory area in purple. Premotor area in pink. The psychic portions of the somesthetic and visual areas are in lighter tints.

Ablation of *area 24* in monkeys has a striking effect on behaviour and conduct.‡ Fear and anxiety reactions are lost and the animal appears to be apathetic towards its fellows and its environment. It has been suggested that the beneficial effects of prefrontal lobotomy obtained in some cases of very serious mental disturbance are to be ascribed to section of the connexions of *area 24*.

Area 23 lies immediately behind *area 24* (fig. 891) but is separated from the sulcus cinguli by *area 31*. It differs from *area 24* in possessing well marked granular layers. Afferent fibres are received from the anterior nucleus of the thalamus, but nothing is known concerning its efferent connexions.

The **orbito-frontal area** includes the medial frontal gyrus and the gyri on the orbital surface of the frontal lobe. The medial frontal gyrus contains extensions from *area 8* and from the frontal area round the supero-medial border of the hemisphere, together with *area 32*, which lies immediately outside the anterior portion

* W. Penfield and T. Rasmussen, *The Cerebral Cortex in Man*, New York, 1950.

† W. E. Le Gros Clark, *loc. cit.*, p. 1004.

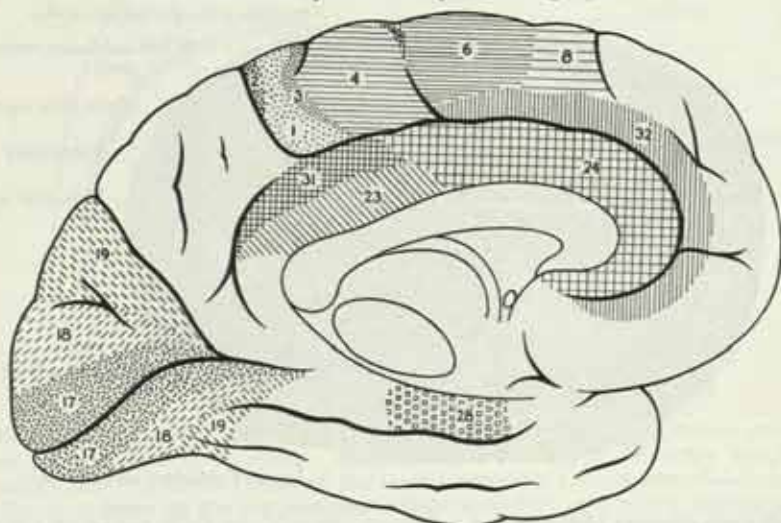
‡ W. K. Smith, *J. Neurophysiol.*, 8, 1945; and A. A. Ward, jr., *Res. Publ. Ass. nerv. ment. Dis.*, 27, 1948.

of the sulcus cinguli (fig. 891). *Area 8* and the frontal area have already been discussed (pp. 1042 and 1043).

Area 32 receives *afferent fibres* from *areas 4s, 8, 2, 19* and *24*, but nothing is yet known concerning its *efferent fibres* or its functional significance.

Of the gyri on the orbital surface of the frontal lobe, only *area 13* (the posterior orbital gyrus) calls for consideration in the present state of our knowledge. This area appears to be predominantly concerned with visceral and vasomotor activities and with respiration and is claimed by some as the site of the cortical representation of the vagus nerve.* It receives *afferent fibres* from the medial nucleus of the thalamus to which it also sends *efferent fibres*. When stimulated by application of strychnine it 'fires off' the putamen of the lentiform nucleus and the caudate nucleus of both sides, the corresponding gyrus of the opposite side and several of the hypothalamic nuclei, including the supra-optic nucleus. In view of the connexion of the last-named with the posterior lobe of the hypophysis (p. 1015), it has been suggested that the posterior orbital gyrus is implicated in those cases where severe emotional disturbances are followed by anuria.

FIG. 891.—Some of the cyto-architectural areas on the medial surface of the left cerebral hemisphere. Compare with fig. 890.



Note.—The numerals used in the figure are identification labels only; frequent references are made to them in the text. Observe that many of the areas are continuous with areas similarly numbered on fig. 889.

The Suppressor Areas.†—In recent years many observers have reported that electrical stimulation of a narrow strip of cortex lying along the anterior border of the motor area (shown as *4s* in fig. 889) results in suppression, lasting ten minutes or longer, of all motor activities and, in many cases, in the cessation of the electrical activity of the whole cortex. This strip has been termed a *suppressor strip* (band or area) and four other similar areas (*areas 8, 2, 19* and *24*) have subsequently been identified. An extensive literature has already grown up on the subject, but it would be premature, at this stage, to include any detailed description in a student's Text-book of Human Anatomy, since other equally reliable observers have been unable to confirm the suppressor effect on electrical stimulation of the areas mentioned.

Further, when the stimulating electrodes were placed in position first and the animal then allowed to recover completely from the effects of the anaesthetic,‡ no suppression of motor or other cortical activity could be recorded on stimulation, so long as the animal remained fully conscious, but, subsequent to the administration of dial—the anaesthetic commonly used in these experiments—the suppressor effect resulted from renewed stimulation.

In the light of these inconsistent findings, the whole subject of 'suppression' obviously requires further clarification and intensive investigation.

* P. Bailey and W. H. Sweet, *J. Neurophysiol.*, **3**, 1940.

† M. Hines, *Amer. J. Physiol.*, **116**, 1936; P. C. Bucy, edit. *The Precentral Motor Cortex*, Univ. of Illinois Press, 1944; and W. S. McCulloch, *Res. Publ. Assoc. nerv. ment. Dis.*, **27**, 1948.

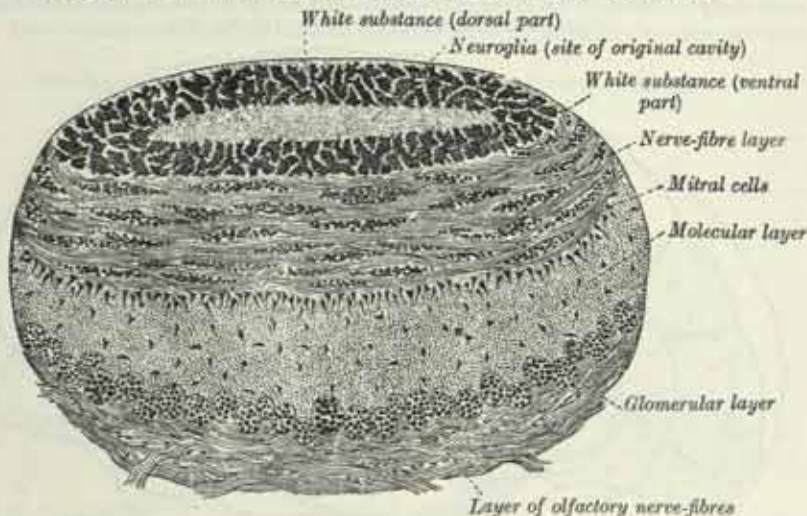
‡ G. Clark, K. L. Chow, C. C. Gillespy and D. A. Klotz, *J. Neurophysiol.*, **12**, 1949.

When studying the various cortical areas and the functions with which they are predominantly associated, the reader must be on his guard against the assumption that the areas are independent units, working in water-tight compartments. Far from being in any way independent, the areas are so interconnected that the functions of the brain are always carried out by two or more of them working in perfect harmony with one another.

In addition to the universally accepted motor and somesthetic areas, certain supplementary motor areas have been described* in the paracentral lobule, and secondary motor and somesthetic areas in the upper lip of the posterior limb of the lateral sulcus. These areas have features which render them difficult to interpret and further investigation is required before more can be said about them in a textbook intended primarily for students.

The Structure of the Rhinencephalon.—The laminated arrangement which is characteristic of the cerebral cortex is considerably modified in the rhinencephalon. It is found in a different form in the olfactory bulb, but it is almost unrecognisable in

FIG. 892.—A coronal section through the olfactory bulb. (Schwalbe.)



the indusium griseum of the corpus callosum, and it is archaic in type in the dentate gyrus and the hippocampus.

Actually, little is known about the sense of smell and even the precise character of olfactory stimulation, which is commonly regarded as stimulation of the olfactory cells in the nasal mucosa by direct contact with substances in solution, has not yet been demonstrated unequivocally. There is a wide range of variation in individual acuity of smell and adaptation to continuing olfactory stimuli is very rapid. Although, as indicated above, secondary pathways connect olfactory cortical areas with the thalamus, neither the thalamus nor the metathalamus acts as a relay station for incoming impulses on their path to the cortex and in this respect smell differs from the other special senses.

The olfactory bulb.—In many animals the olfactory bulb contains a cavity which communicates with the lateral ventricle through a hollow olfactory tract. In man the walls of the bulb become thickened, the ventral wall more so than the dorsal wall, and the site of the cavity is occupied by a mass of neuroglia. A section through the bulb demonstrates the presence of the following layers: (1) a layer of *olfactory nerve-fibres*.—These fibres are the non-medullated axons of the olfactory cells in the nasal mucosa, and they reach the bulb by passing through the cribriform plate of the ethmoid bone. They ascend into (2) the *glomerular layer*, where they interlace with the terminals of stout, descending dendrites from the mitral cells, forming a compact layer of small tufts, termed 'glomeruli'. (3) The *molecular layer* contains the densely packed *mitral cells*, each of which sends a dendrite down into a 'glomerulus', while its axon ascends into (4), the *nerve-fibre layer*. In this layer the medullated axons of the mitral cells turn backwards to enter the olfactory tract and are mingled with incoming fibres from the other olfactory bulb, which have crossed in the anterior commissure. (5) The *neuroglial layer* has already been mentioned.

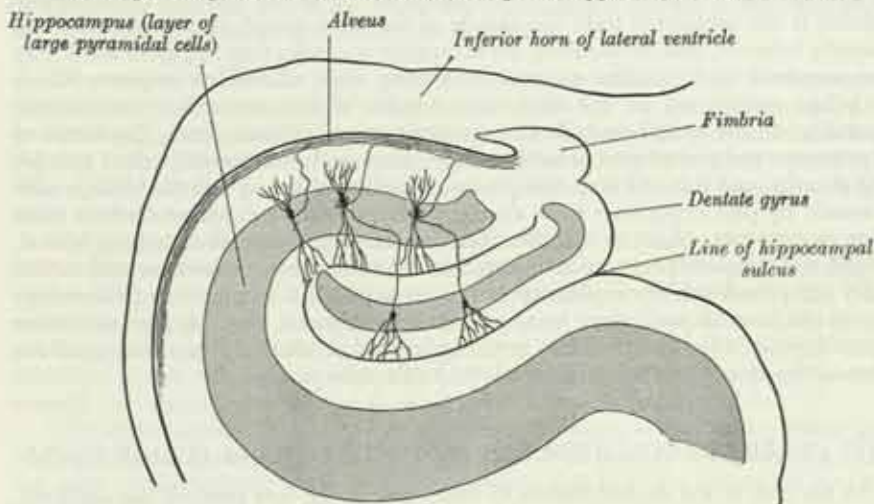
* W. Penfield and T. Rasmussen, *The Cerebral Cortex in Man*, New York, 1950.

The *anterior perforated substance* is irregularly broken up by bands of fibres and blood-vessels so that its structure shows no constant or regular arrangement. Its olfactory portions are poorly developed areas in the human brain.

The **piriform area** shows a definitely stratified arrangement, which differs in certain respects from the cortex of the neopallium. The molecular layer is unusually deep and contains a large number of tangential fibres. The adjoining layer contains two varieties of cells, each arranged in clumps or cell-nests. The third layer is deep, and the cells which it contains are chiefly pyramidal in shape, and their apices point obliquely to the surface. The fourth layer is shallower and contains remarkably few cells. The fifth layer is thicker and contains cells which resemble the pyramidal elements of the third layer. A sixth layer, of fusiform cells, is also present.

This area receives the olfactory neurones of the second order and sends most of its efferent fibres into the immediately adjoining part of the parahippocampal gyrus (*area 28*), (p. 1033).

FIG. 893.—Diagram of a coronal section through the hippocampus. After Villiger.



The **hippocampus** is more primitive in its structure than the piriform area and consists essentially of three layers. It represents a portion of the cortex which has been rolled into the inferior horn of the lateral ventricle and its superficial cortical layer lies in relation to the hippocampal sulcus anteriorly and to the dentate gyrus posteriorly. The superficial or *molecular layer* is unusually deep and is densely packed with tangential fibres. This is succeeded by a thick layer of *large pyramidal cells*, which give off long apical dendrites into the molecular layer. Their axons run centrally through the succeeding polymorphous layer and pass into the subjacent white matter, which here constitutes the *alveus*. The third layer contains *polymorphous cells*, some of which are cells of Martinotti. Little is known concerning the incoming fibres to the hippocampus, except for those derived from the adjoining part of the parahippocampal gyrus (*area 28*), mentioned above.

The white fibres of the alveus cover the polymorphous layer and separate it from the ependyma on the free, ventricular surface of the hippocampus (fig. 893).

The *dentate gyrus* also consists of three layers, viz. a molecular layer, a granular layer and a polymorphous layer. The axons of the cells in the granular layer pass to reach the pyramidal layer of the hippocampus, where they terminate by arborising round the large pyramidal cells. The polymorphous layer contains many cells which send their axons through the adjoining layers of the hippocampus to reach the alveus.

The curious interlocking which occurs in the region of the hippocampus and the dentate gyrus (fig. 893) requires explanation. As the hippocampal formation becomes defined, the cells which ultimately form the dentate gyrus lie on the fringe of the pallium and immediately adjoin the chorioid fissure. The constituent cells of the formation proliferate rapidly, and as a result they form an elevation which protrudes into the cavity of the ventricle. The cells which form the intermediate layer of the hippocampus are directly continuous with the granular layer of the neopallium on the one hand and with the intermediate layer of the dentate gyrus on the other. As growth proceeds, however, the continuity with the cells of the dentate gyrus is broken, and the latter, as seen on transverse section (fig. 893), forms an isolated strip which has all the appearance of being inserted, secondarily, into the infolded cortex of the hippo-

campus. As a result, the molecular layer of the dentate gyrus is in direct contact with the corresponding layer of the hippocampus. The hippocampal sulcus, when it is present, intervenes between them. The polymorphous layer of the dentate gyrus is also in contact with the molecular layer of the hippocampus, which has extended over its dorsal, or superior, aspect (fig. 893).

MYELINATION

Flechsig showed that the white fibres of the cerebral hemisphere do not all acquire their myelin sheaths at the same period. The process commences in the eighth month of intrauterine life and involves first the afferent fibres passing to the somesthetic area in the postcentral gyrus and the afferent fibres to the hippocampal formation. While the nerve-fibres in these areas are receiving their medullary sheaths, the process commences in the afferent fibres leading to the visuosensory and the audiosensory cortical areas. Myelination of the great, efferent corticospinal pathway is not completed until the middle of the third month after birth. As it is generally believed that nerve-fibres are incapable of conducting impulses until they have acquired their myelin sheaths, it follows that all the movements which the infant carries out in the first two months of life are reflex movements, depending on the spinal medulla and the brain-stem. Subsequently the fibres of the premotor and somesthetic areas and of the visuo- and audiotpsychic areas acquire their sheaths, and it is not until this process is well established that the child is able to benefit by past experience or is able to perform voluntary acts as distinct from reflex movements. Last of all, the fibres of the large association areas (frontal, parietal and temporal) become myelinated and in these areas the process may not be finally completed until the eighteenth year or even later. Complete mental development is not possible until these areas can be utilised, and it would appear that there is considerable individual variation in the age period at which the myelination of the fibres of the association areas is completed. (See also p. 1078.)

THE CEREBRAL COMMISSURES AND THE SEPTUM PELLUCIDUM

At the end of the second month of development the two cerebral hemispheres, whose large cavities communicate with the anterior part of the third ventricle, are connected to each other by the anterior wall of the third ventricle (*lamina terminalis*) and by the anterior parts of its roof and floor. The roof at this stage is formed of a single layer of ependyma only and remains so throughout life. It therefore does not offer any pathway to fibres which, arising on one side of the cerebrum, are seeking to reach the other. The floor, on the other hand, is actively concerned with the development of the optic chiasma, the tuber cinereum and the hypophysis. It is therefore to the undeveloped region of the *lamina terminalis* that the commissural fibres travel in order to gain the opposite side. The earliest commissural fibres to develop are associated, as might be expected, with the rhinencephalon, and they constitute two distinct bundles. The *anterior commissure* occupies the lower part of the *lamina terminalis* and consists of fibres which connect the olfactory bulbs, the olfactory portions of the anterior perforated substance of both sides and the piriform areas. The second commissural bundle connects the two fornix systems, and through them the hippocampal formations, and naturally traverses the upper part of the *lamina*. It is termed the *commissure of the fornix*. The development of these commissures leads to local thickenings of the *lamina terminalis*, and when the commissural fibres of the neopallium develop, they follow the paths which have already been prepared. A few fibres from the temporal area join the anterior commissure, but the bulk of the neopallial fibres accumulate on the dorsal aspect of the commissure of the fornix and develop into the *corpus callosum*. In the fifth month the *corpus callosum* forms a curved band which projects forwards from the upper part of the *lamina terminalis* and is in close relationship at its posterior end with the upper and posterior part of the commissure of the fornix. The cortical area which occupies the angular interval below the projecting anterior end of the *corpus callosum* is named the *paraterminal gyrus* and it extends downwards in front of the whole length of the *lamina terminalis*. With the subsequent formation of the rostrum, which recurves downwards and backwards, the connexion between the upper part of the *paraterminal gyrus* and the rest of the area becomes severed. The included portion is thinned out and stretched by the general growth of the *corpus callosum* and the fornix and becomes the *septum pellucidum*.*

* A somewhat different view of the origin of the septum pellucidum is given by J. Maclaren Thompson, *J. Anat.*, Lond., 67, 1932.

While these changes, which have not yet been observed in their entirety, are occurring at the anterior end of the corpus callosum, its posterior end increases rapidly in bulk and together with the commissure of the fornix is carried backwards above the epithelial roof of the third ventricle. As it passes backwards, it lies above the line of the chorioid fissure and invades the upper part of the hippocampal formation, which consequently becomes thinned out on its surface to form the indusium griseum. Owing to this backward growth, the corpus callosum and the commissure of the fornix form an additional and secondary roof for the third ventricle. It must be remembered, however, that the narrow interval between the commissures above and the epithelial roof of the third ventricle below is really an extra-cerebral space and that the transverse fissure, which lies below the splenium of the corpus callosum and leads into this interval, is not a cerebral fissure in the true sense of the word.

In its backward growth the corpus callosum does not extend so far as the lower part of the chorioid fissure, and it therefore makes no inroad into that part of the hippocampal formation which is associated with the inferior horn of the ventricle and which gives rise to the dentate gyrus and the hippocampus. In the light of the development of the corpus callosum, the continuity of the hippocampus and the dentate gyrus with the indusium griseum (p. 1033) becomes intelligible.

The **corpus callosum** is the great transverse commissure which connects the cerebral hemispheres and roofs in the lateral ventricles. A good conception of its position and size is obtained by examining a median sagittal section of the brain (fig. 873). It forms an arched structure about 10 cm. in length, its anterior end being about 4 cm. from the frontal poles and its posterior end about 6 cm. from the occipital poles of the hemispheres.

The *genu*, which forms the anterior end, is bent downwards and backwards in front of the septum pellucidum and, diminishing rapidly in thickness, is prolonged backwards to the upper end of the lamina terminalis as the *rostrum*. The *trunk* arches backwards with an upward convexity and terminates posteriorly in the *splenium*, which is the thickest part of the corpus callosum. A sagittal section of the splenium shows that the posterior end of the corpus callosum is bent forwards acutely, the upper and lower parts being applied closely to each other.

The upper surface of the *trunk* of the corpus callosum is covered by a thin layer of grey substance, termed the *indusium griseum*. This grey covering extends round the *genu* to the inferior surface of the *rostrum*, and in it are imbedded two fine longitudinal bundles of fibres on each side, which are termed the medial and lateral longitudinal striæ (p. 1033); posteriorly the indusium griseum is continuous with the dentate gyrus and the hippocampus through the gyrus fasciolaris.

In the median plane the trunk of the corpus callosum forms the floor of the longitudinal fissure, and is related to the anterior cerebral vessels and to the lower border of the falx cerebri, which may come into actual contact with it posteriorly (fig. 1112). On each side of the median plane the trunk is overlapped by the gyrus cinguli, from which it is separated by the slit-like callosal sulcus.

The inferior surface of the trunk is concave in its long axis and convex from side to side. In the median plane, it gives attachment to the septum pellucidum anteriorly, and the extent of this attachment depends on the length of the septum (fig. 873). Posteriorly it is fused with the body of the fornix and the commissure of the fornix. On each side of the median plane, the inferior surface of the trunk forms the roof of the lateral ventricle (fig. 896) and is covered with the ventricular ependyma.

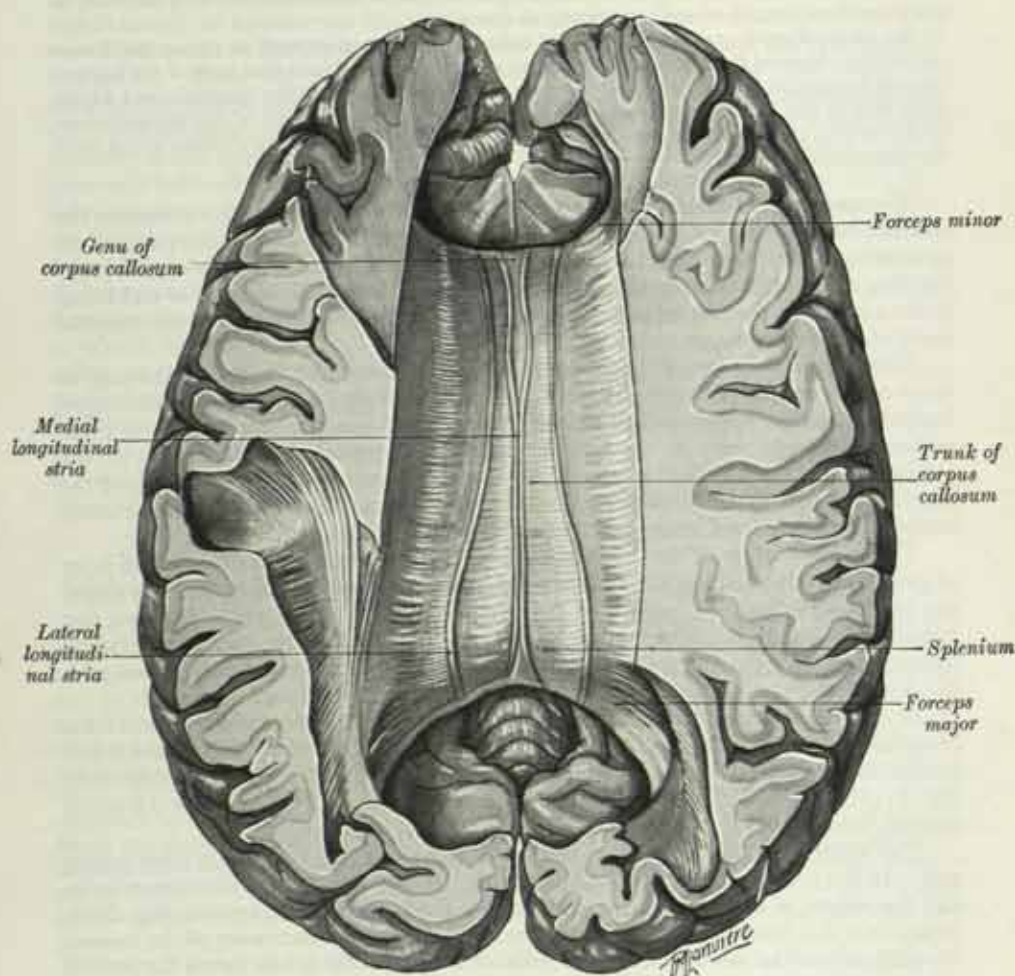
The *genu* is continuous above with the trunk and below with the *rostrum*. Its anterior surface, which is in relation to the anterior cerebral vessels, is covered with the indusium griseum and the longitudinal striæ. Its posterior surface gives attachment to the septum pellucidum in the median plane, and on each side it forms the anterior wall of the anterior horn of the lateral ventricle.

The *rostrum* connects the *genu* to the upper end of the lamina terminalis. In the median plane its superior surface gives attachment to the septum pellucidum and, on each side, forms the narrow floor of the anterior horn of the lateral ventricle (fig. 907). On the inferior surface of the rostrum the indusium griseum and the longitudinal striæ are carried backwards to the upper end of the paraterminal gyrus.

The *splenium* overhangs the posterior ends of the thalami, the pineal body and the tectum of the mid-brain. It is, however, separated from them by a number of structures. On each side of the median plane the crus of the fornix and the gyrus fasciolaris (fig. 895) curve upwards to reach the splenium. The crus of the fornix continues forwards on the under surface of the trunk, but the gyrus fasciolaris

passes round the splenium, rapidly tapering off and fading away into the indusium griseum. In the median plane, the tela chorioidea passes forwards below the splenium through the transverse fissure, and the internal cerebral veins emerge from between its two layers and unite to form the great cerebral vein. Above, the splenium is covered with the indusium griseum and is related to the falx cerebri and the inferior sagittal sinus in the median plane, and to the gyrus cinguli on each side.

FIG. 894.—The corpus callosum. Exposed from above.



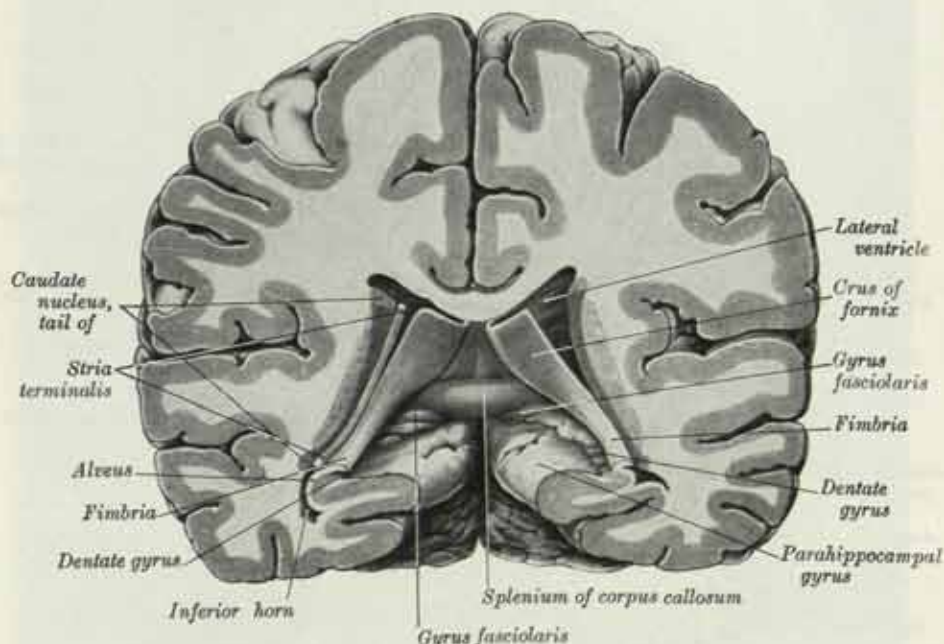
Posteriorly the splenium is related to the free margin of the tentorium cerebelli, the great cerebral vein and the beginning of the straight sinus.

The fibres of the corpus callosum radiate into the white matter of the hemisphere on each side and pass to the various parts of the cerebral cortex. The fibres of the rostrum pass laterally below the anterior horns of the lateral ventricles, and connect the orbital surfaces of the two frontal lobes. The fibres of the genu curve forwards and connect the lateral and medial surfaces of the two frontal lobes, constituting the *forceps minor*. The fibres of the trunk pass laterally and intersect the projection fibres of the corona radiata (fig. 860). They connect wide cortical areas of the two hemispheres to one another. Those fibres of the trunk and of the splenium which together form the roof and lateral wall of the posterior horn, and the lateral wall of the inferior horn of the ventricle constitute the *tapetum* (p. 1058). The remaining fibres of the splenium curve backwards and medially into the occipital lobes and form the *forceps major*. This large bundle of fibres bulges into the upper part of the

medial wall of the posterior horn of the ventricle and forms a curved elevation which is termed the *bulb of the posterior horn*.

Despite the great size of the corpus callosum and the enormous number of commissural fibres that it contains, very little information is available concerning its functional significance, apart from the obvious inference that it links the two hemispheres together and appears to ensure that they act as a single entity. Cases of complete congenital absence of the corpus callosum are recorded from time to time—the condition is a rare one—but the defect is usually found at autopsy, and the clinical history has not shown any characteristic feature which has led to diagnosis of the condition during life. The individuals concerned have usually been insane but were able to perform manual work efficiently under supervision. In recent years large portions, and in some cases the whole of the corpus callosum, have been divided as a therapeutic measure with surprisingly little disturbance of function.*

FIG. 895.—A dissection of a coronal section of the brain to display the splenium of the corpus callosum from in front.



The posterior portions of the thalami have been removed. Observe that the arrangement of the fimbria relative to the dentate gyrus was different on the two sides of this specimen.

The **anterior commissure** is a bundle of white fibres which crosses the median plane in front of the columns of the fornix in the anterior wall of the third ventricle (fig. 870). On sagittal section it is oval in shape, its long diameter being vertical and measuring about 5 mm. Its constituent fibre bundles are twisted like the strands of a rope, and they curve backwards and laterally, forming a deep groove on the inferior aspect of the anterior part of the corpus striatum (fig. 896). Many of the fibres belong to the rhinencephalon and connect the olfactory bulbs and the piriform areas. Others belong to the neopallium and can be traced into the temporal lobes, where they spread out like the frayed end of a rope so that their precise connexions are difficult to determine.

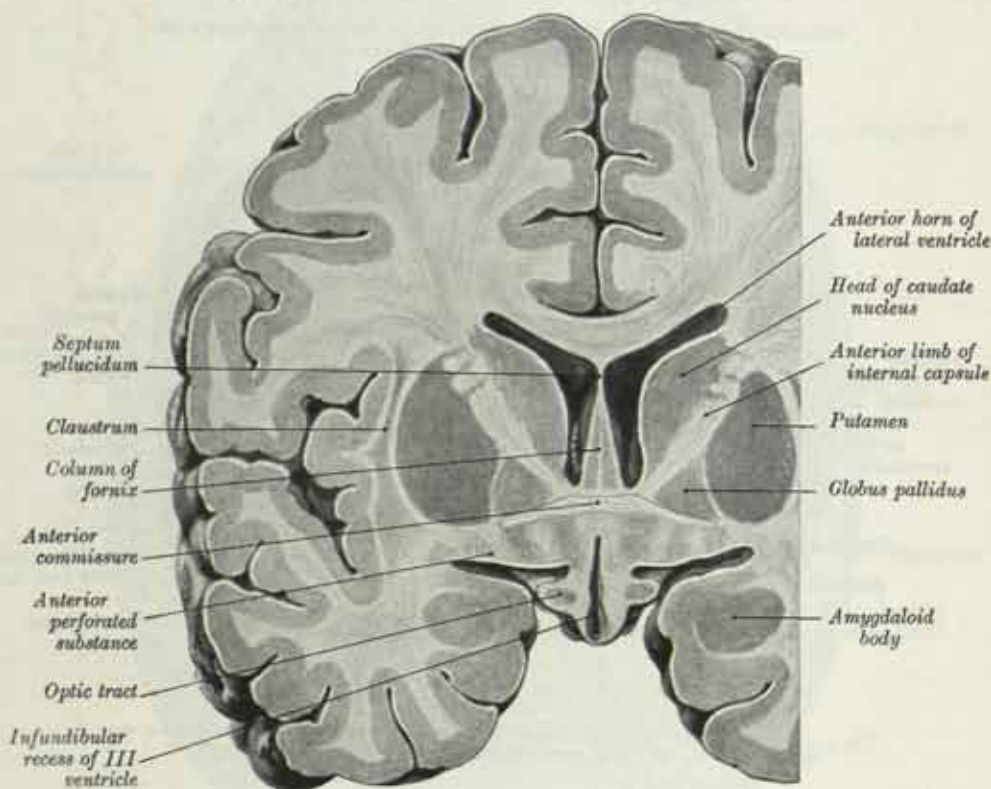
The **commissure of the fornix (hippocampal commissure)** forms a thin sheet of transverse fibres which connects the medial edges of the crura of the fornix and is closely applied to the under surface of the posterior part of the trunk of the corpus callosum. Its constituent fibres are derived from the pyramidal cells of the hippocampus and traverse the alveus and the fimbria in order to reach the crus of the fornix. Having crossed the median plane in the commissure, they retrace their course on the opposite side and terminate in the molecular layer of the hippocampus.

* A. J. Akelaitis, et al., *Arch. Neurol. Psych.*, 47, 1942.

The **septum pellucidum** is a thin vertical partition, consisting of two laminae, separated throughout a greater or lesser part of their extent by a narrow interval, termed the *cavity of the septum pellucidum*, which does not communicate with the ventricles of the brain. The septum is triangular in form, with its base in front and its apex behind. It is attached above to the inferior surface of the trunk of the corpus callosum; below and behind, to the anterior part of the fornix; below and in front, to the upper surface of the rostrum of the corpus callosum. The lateral surface of each lamina takes part in the formation of the medial wall of the anterior horn and body of the lateral ventricle, and is therefore covered with ependyma.

The laminae contain both grey and white matter, but they are so thin that their structure does not afford much help in determining their phylogenetic history. The development of the septum pellucidum is referred to on p. 1052.

FIG. 896.—A coronal section passing through the brain just behind the optic chiasma and exposing the anterior commissure as it crosses the median plane.



THE INTERIOR OF THE HEMISPHERES

The **lateral ventricles** (figs. 897-901).—The two lateral ventricles are irregular cavities situated in the lower and medial parts of the cerebral hemispheres, one on each side of the median plane. They are almost completely separated from each other by the *septum pellucidum*, but they communicate with the third ventricle and indirectly with each other through the *interventricular foramen* (p. 1019). They are lined with ciliated epithelium (*ependyma*) and contain cerebrospinal fluid, which, even in health, may be secreted in considerable amount. Each lateral ventricle consists of a *central part* and three *cornua* or *horns* (anterior, posterior and inferior) (fig. 899 and Pl. XXI and XXII).

The **central part** (fig. 899) of the lateral ventricle extends from the interventricular foramen to the splenium of the corpus callosum. It is an irregularly curved cavity, triangular on transverse section, with a roof, a floor, and a medial wall. The roof is formed by the under surface of the corpus callosum; the floor, which is concave upwards and medially, is formed by the following parts, named in their order of position from the lateral to the medial side: the caudate nucleus of

PLATE XXI



Lateral radiograph of living head after injection of air into the lateral ventricles through burr holes, both of which are visible near the lambda. (Ventriculogram; Sir Hugh Cairns.)

The body of the ventricle shows a curvature which corresponds very closely with the curvature of the vault of the skull, and its depth increases in the anterior horn. The inferior horn is almost horizontal. In this subject the posterior horn is unusually long.



Antero-posterior radiograph of the head shown in Pl. XXI.

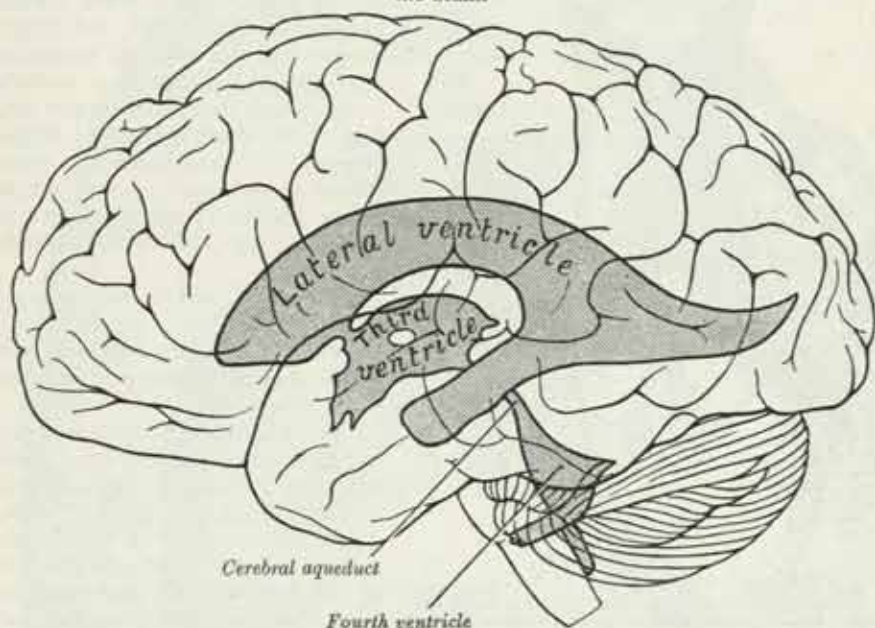
(Ventriculogram : Sir Hugh Cairns.)

The outlines of the bodies and anterior horns of both ventricles are seen separated in the median plane by the shadow of the septum pellucidum, and, directly below it, the cavity of the third ventricle can be recognised.

On the left side of the ventriculogram the burr hole overlaps, very slightly, the lateral wall of the ventricle ; on the right side, it is a little to the lateral side and at a slightly higher level.

the corpus striatum, the stria terminalis and the thalamostriate vein, the lateral portion of the upper surface of the thalamus, the chorioid plexus, and the edge of the fornix. The caudate nucleus becomes rapidly narrower as it is traced backwards in the floor, and its long axis is directed laterally as well as posteriorly. The stria terminalis, a small bundle of white fibres (p. 1033), and the thalamostriate vein occupy a narrow groove which follows the medial border of the caudate nucleus and separates it from the lateral margin of the upper surface of the thalamus. The latter may be almost entirely hidden by the vascular fringe of the chorioid plexus, which invaginates the ependyma into the cavity through the slit-like interval between the edge of the fornix and the upper surface of the thalamus. This ependymal invagination constitutes the chorioid fissure. The body of the fornix becomes wider as it is traced backwards, and its thin, lateral margin lies parallel with the groove for the stria terminalis.

FIG. 897.—A scheme showing the relations of the ventricles to the surface of the brain.



The medial wall is formed by the posterior part of the septum pellucidum. Posteriorly, where the septum pellucidum ends, the roof and the floor meet one another on the medial wall.

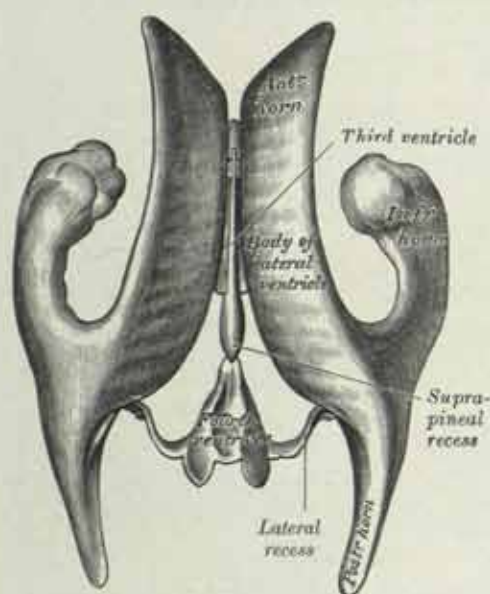
The **anterior horn** (fig. 897) passes forwards, laterally and slightly downwards, into the frontal lobe, curving round the large swelling caused by the head or anterior end of the caudate nucleus. In a coronal section it appears as a triangular slit below the anterior part of the corpus callosum, and it is bounded anteriorly by the posterior surface of the genu of the corpus callosum. The greater part of the floor is formed by the rounded head of the caudate nucleus, but, in its medial portion, a small part is formed by the upper surface of the rostrum of the corpus callosum (fig. 907). The medial boundary is formed by the septum pellucidum.

The **posterior horn** curves backwards and medially into the occipital lobe. Its development is very variable and frequently asymmetrical. Its roof and lateral wall are formed by fibres of the tapetum of the corpus callosum, which separate them from the optic radiation (p. 1064). The splenial fibres which constitute the forceps major pass medial to the posterior horn as they sweep backwards into the occipital lobe. In this part of their course they produce a rounded ridge in the upper part of the medial wall, which is named the *bulb* of the posterior horn. Below the bulb, a second elevation may be identified on the medial wall. It receives the fanciful name of the *calcar avis*, and it corresponds to the infolded cortex of the anterior part of the calcarine sulcus (fig. 900). Posteriorly the lateral and medial walls meet each other.

The **inferior horn** (fig. 901), the largest of the three, traverses the temporal lobe, forming in its course a curve round the posterior end of the thalamus. It passes at first backwards, laterally, and downwards, and then curves forwards to within 2.5 cm. of the temporal pole, its position being fairly well indicated on the surface of the brain by the superior temporal sulcus. A needle, introduced at a trephine hole the centre of which is placed 3 cm. behind and 3 cm. above the centre of the external auditory meatus, and passed in the direction of the tip of the opposite auricle, enters the inferior horn at a depth of 5 cm. from the surface.

The roof of the inferior horn is formed chiefly by the inferior surface of the tapetum of the corpus callosum, but the tail of the caudate nucleus

FIG. 898.—A drawing of a cast of the ventricular cavities. Superior aspect. (Retzius.)



Note.—Where the lateral recess joins the fourth ventricle, the cast shows the curved lateral dorsal recesses of the roof of the ventricle (p. 984) projecting dorsally on each side beyond the posterior margin of the median dorsal recess.

The superior angle of the fourth ventricle and the aqueduct of the midbrain are hidden by the supra-pineal recess.

and the stria terminalis also extend forwards in the roof, at the extremity of which they end in the amygdaloid body. Its floor presents the following parts: the chorioid plexus, the fimbria hippocampi, the hippocampus and the collateral eminence. The chorioid plexus is a vascular fringe which covers the upper surface of the fimbria and the hippocampus. It invaginates the ependymal medial wall of the inferior cornu and so forms the lower or temporal part of the chorioidal fissure.

The fimbria and the hippocampus have already been considered (pp. 1034 and 1035), and a full description of the chorioid plexus will be found on p. 1069.

The *collateral eminence* (fig. 901) is an elongated swelling lying lateral to and parallel with the hippocampus. It corresponds with the middle part of the collateral sulcus, and its size depends on the depth and direction of this sulcus. It is continuous behind with a flattened triangular area, named the *trigonum collaterale*, which forms the floor of the ventricle between the posterior and inferior horns.

The white matter of the hemispheres.—If the upper parts of the hemisphere be sliced off about 1.25 cm. above the corpus callosum, the central white matter of the hemisphere is seen as an oval area surrounded by a narrow convoluted margin of grey matter, and studded with red dots (*puncta vasculosa*) produced by the escape of blood from divided blood-vessels. If the hemispheres be sliced off at the level of the corpus callosum, the white matter of that structure will be seen in continuity with the white matter of the hemisphere on each side. The white matter contains many medullated fibres, of varying size, supported by neuroglia. These fibres may be divided, according to their course and connexions, into three systems: (1) The *commissural fibres* connect corresponding areas in the two hemispheres to each other. (2) The *arcuate fibres* connect different cortical areas of the same hemisphere to one another; some of them are collaterals of the projection and commissural fibres, but the majority are independent axons. (3) The *projection fibres* connect the cerebral cortex with the grey matter of the brain-stem and the spinal medulla.

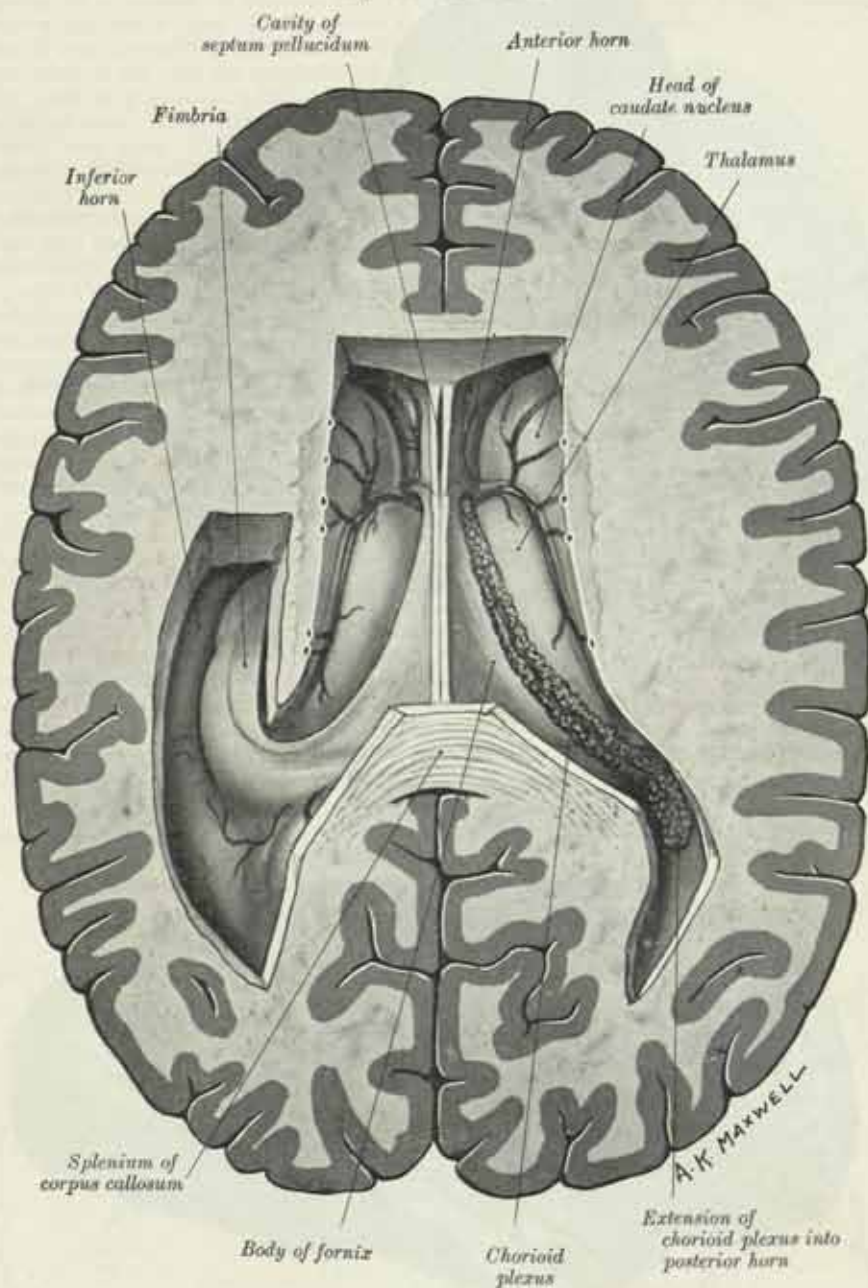
(1) The **commissural fibres** have already been considered (p. 1052).

(2) The **arcuate (association) fibres**, which are all ipsilateral, are of two kinds: (a) short arcuate fibres, connecting adjacent gyri to one another; (b) long arcuate fibres, connecting more widely separated gyri to one another.

The *short arcuate fibres* may be intracortical or they may lie immediately beneath the cortex and connect adjacent gyri, some merely passing from one wall of a sulcus to the other.

The *long arcuate fibres* group themselves, somewhat indistinctly, into bundles, which can be dissected in the formalin-hardened brain after the cortex and the sub-

FIG. 899.—The central parts and the anterior horns of the lateral ventricles. Exposed from above.

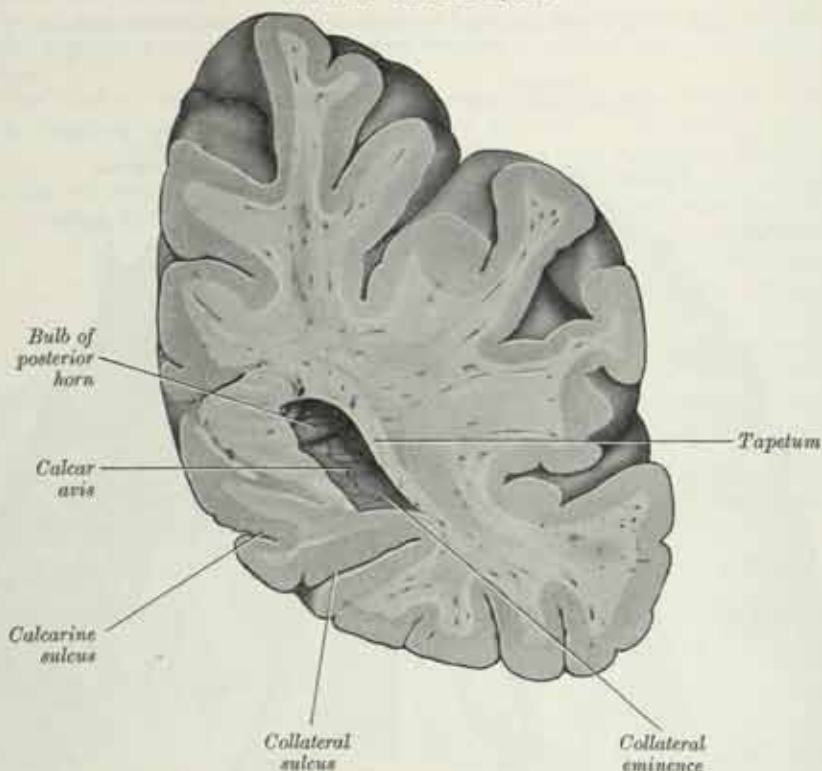


jacent short arcuate fibres have been removed. The fibres in each fasciculus show considerable variation in length, and the longest are always situated in the deepest part of the bundle. Concerning the precise connexions of these fibre bundles very little accurate information is at present available for histological methods are unable to demonstrate them throughout the whole of their length. The following fasciculi can be distinguished: (a) the uncinate fasciculus; (b) the cingulum; (c) the superior

longitudinal fasciculus; (d) the inferior longitudinal fasciculus; (e) the fronto-occipital fasciculus.

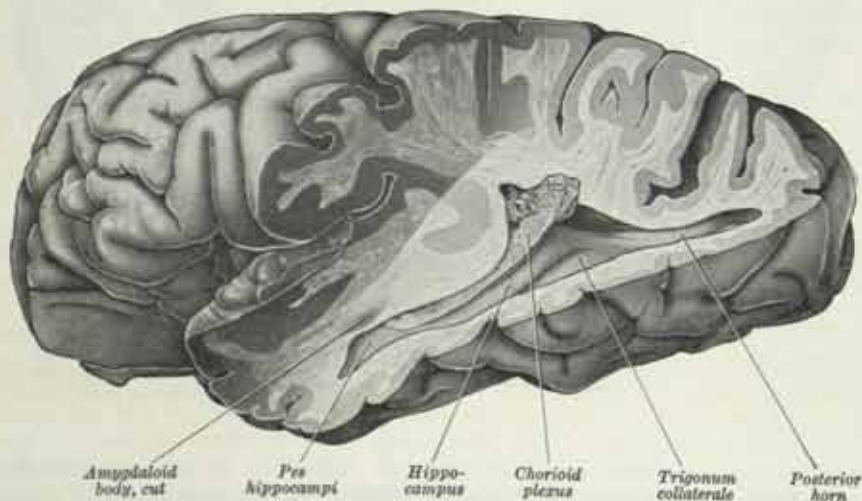
(a) The *uncinate fasciculus* connects Broca's area (p. 1043) and the gyri on the orbital

FIG. 900.—A coronal section through the posterior horn of the left lateral ventricle. Anterior aspect.



surface of the frontal lobe with the cortex of the temporal pole and the area immediately adjoining. The fibres follow a sharply curved course and cross the floor of the

FIG. 900a.—The inferior and posterior horns of the lateral ventricle, exposed from the left side.



stem of the lateral sulcus. They are related to the antero-inferior part of the insular area (figs. 902 and 903).

(b) The *cingulum* is a long, curved bundle which commences on the medial

surface of the hemisphere below the rostrum of the corpus callosum. It lies within the gyrus cinguli and so follows the curve of that gyrus. Inferiorly it enters the parahippocampal gyrus and spreads out so as to reach the adjoining parts of the temporal lobe.

(c) The *superior longitudinal fasciculus* is the largest of all the arcuate bundles. It commences in the anterior part of the frontal region and arches backwards above the insular area and lateral to the lower part of the corona radiata (p. 1062). After giving off a number of fibres to the occipital cortex (probably *area 18*), it curves downwards and forwards behind the insular area and spreads out into the temporal lobe. Like the other long arcuate fasciculi, it constantly receives new fibres throughout its whole extent and gives off fibres to the adjoining cortex. Its constituent fibres are so intermingled that it is quite impossible to determine their precise connexions by gross methods (fig. 903) and for this purpose the dissecting microscope is of no real help.

(d) The *inferior longitudinal fasciculus* commences near the occipital pole and its fibres are derived chiefly from *area 18*. They sweep forwards, separated from the posterior horn of the lateral ventricle by the fibres of the optic radiation and the commissural fibres of the tapetum, and after being crossed by the superior longitudinal fasciculus, they are distributed throughout the temporal lobe.

(e) The *fronto-occipital fasciculus* commences at the frontal pole and passes backwards on a deeper plane than the superior longitudinal fasciculus and separated from it by the lower part of the corona radiata (*vide infra*). It associates itself with the lateral border of the caudate nucleus, and is therefore closely related to the central part of the lateral ventricle. Posteriorly its fibres radiate into the occipital and temporal lobes in a fan-shaped manner, passing lateral to the posterior and inferior horns, and intersecting and mingling with the fibres of the tapetum of the corpus callosum.

(3) The **projection fibres** connect the cerebral cortex with the lower parts of the brain (including the diencephalon) and the spinal medulla, and include both corticofugal and corticopetal fibres.

FIG. 901.—The posterior and inferior horns of the right lateral ventricle. Exposed from above.

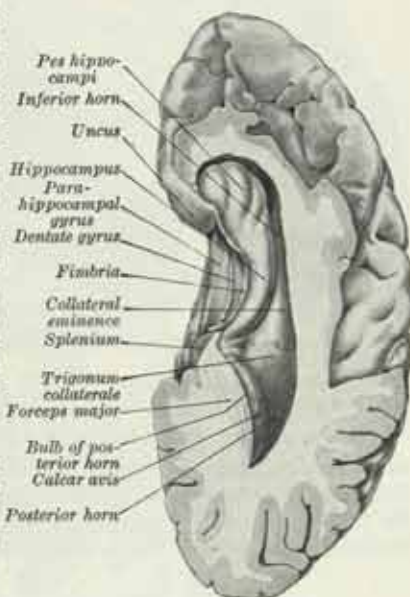


FIG. 902.—A diagram showing the principal system of arcuate fibres in the cerebrum.

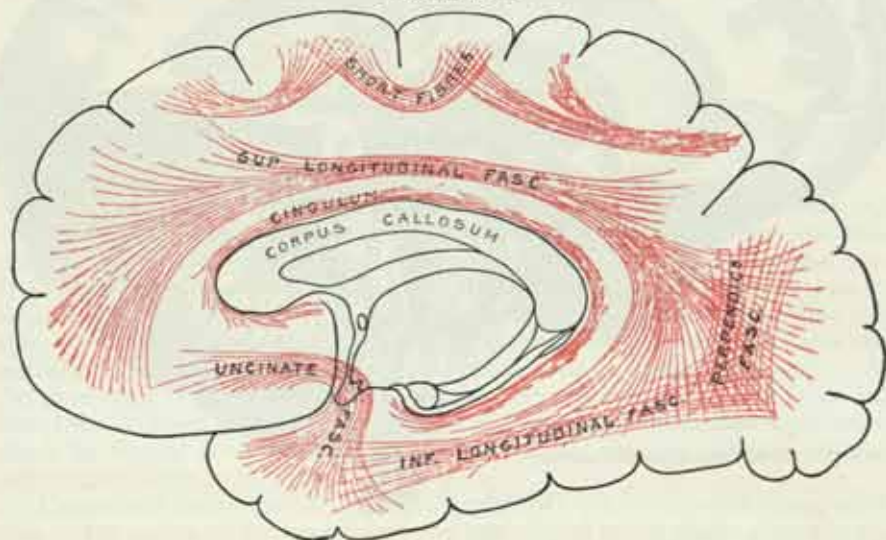
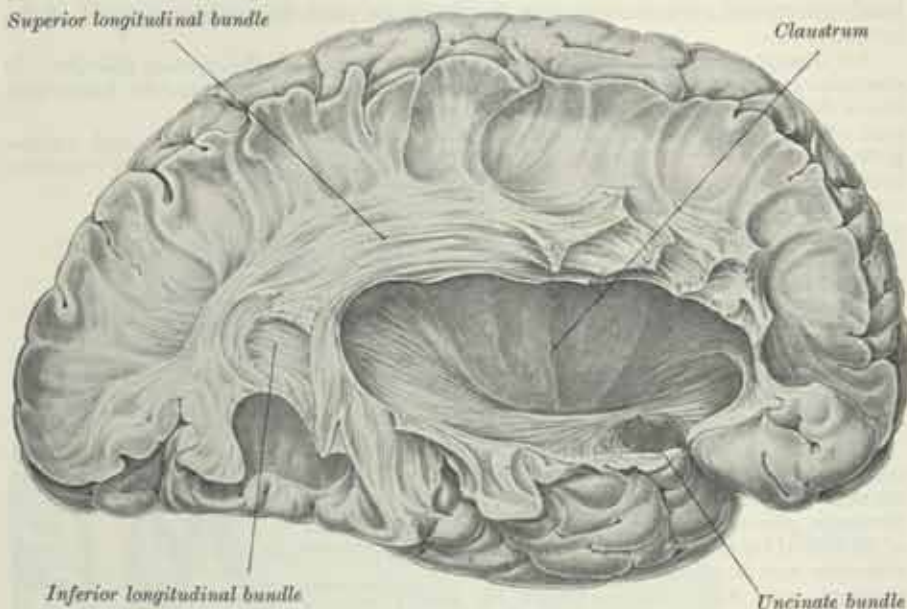
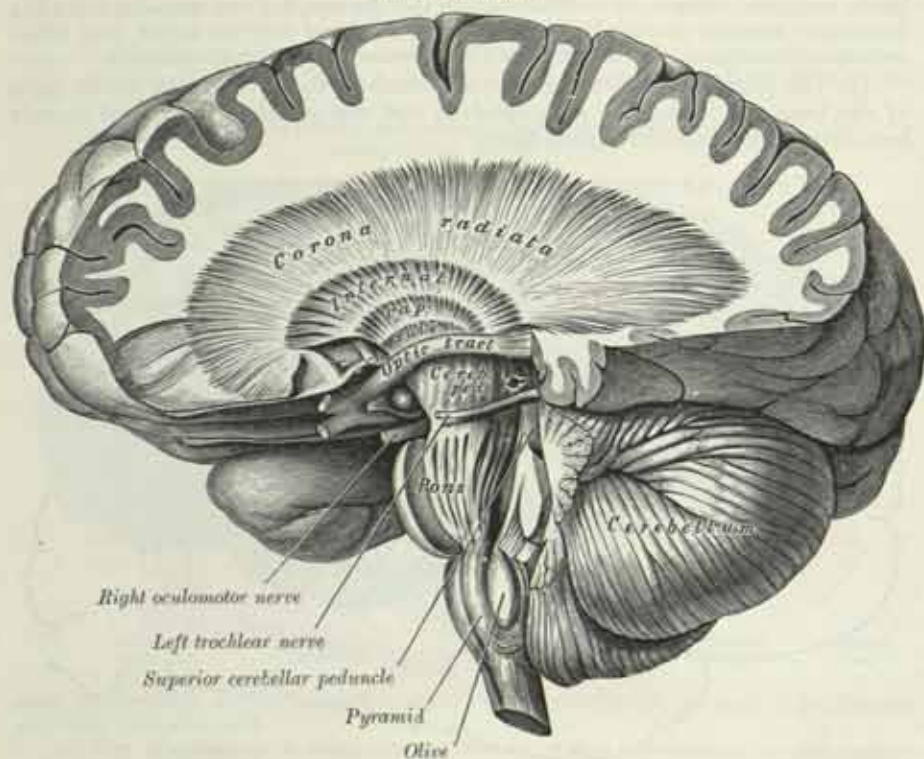


FIG. 903.—A dissection showing some of the long arcuate bundles of the right cerebral hemisphere.



The *projection fibres of the neopallium* converge from all directions on the corpus striatum (fig. 904). For the most part they lie deep to the arcuate fibres, and they intersect the commissural fibres of the corpus callosum and the anterior commissure. As they approach the periphery of the corpus striatum, they emerge from this intersection and form the *corona radiata*. The medial aspect of the corona radiata

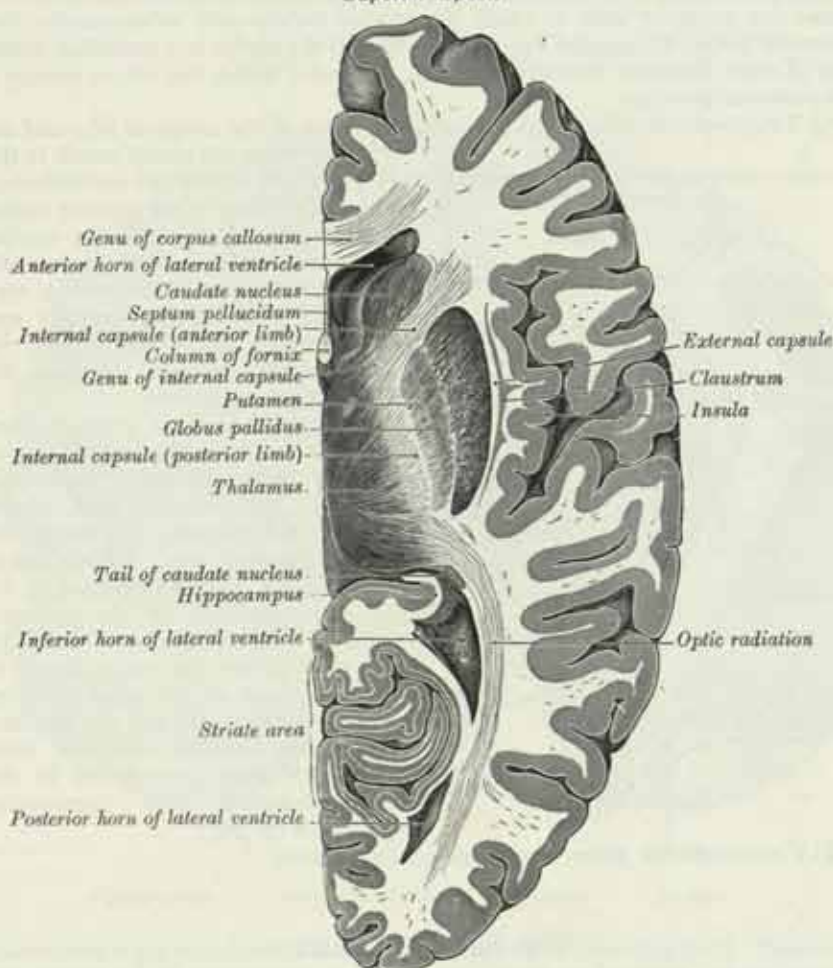
FIG. 904.—A dissection showing the course of the corticospinal fibres.
(E. B. Jamieson.)



is separated from the lateral ventricle by the fronto-occipital fasciculus, and its lateral aspect is covered by the superior longitudinal fasciculus. Below, the corona radiata is directly continuous with the internal capsule, a thick, curved band of white matter which comprises all the projection fibres of the neopallium, and which cuts into the corpus striatum, dividing it almost completely into two parts, viz. the lentiform and the caudate nuclei.

A transverse, horizontal section through the cerebral hemisphere shows the **internal capsule** as a broad band of white fibres, bent with an outward concavity, which accommodates itself to the convex medial surface of the lentiform nucleus

FIG. 905.—A horizontal section through the right cerebral hemisphere.
Superior aspect.



(fig. 905). It can therefore be divided into an *anterior limb*, a *genu*, a *posterior limb* and a *sublentiform part*. The anterior limb is interposed between the lentiform nucleus on the lateral side and the head of the caudate nucleus on the medial side. The posterior limb has the thalamus on its medial side and the lentiform nucleus on its lateral side. The fibres of the internal capsule continue to converge as they pass downwards, and at the same time the frontal fibres tend to pass backwards and medially, while the temporal and occipital fibres pass forwards and laterally. At the lower limit of the lentiform nucleus, they are crossed by the optic tract and enter the mid-brain. The corticofugal fibres enter the base of the cerebral peduncle, where the frontal fibres are placed to the medial side and the temporal, parietal and occipital fibres to the lateral side.

The *anterior limb* of the internal capsule contains: (1) *frontopontine fibres*, which arise in the cortex of the frontal area and are relayed in the nuclei pontis to the

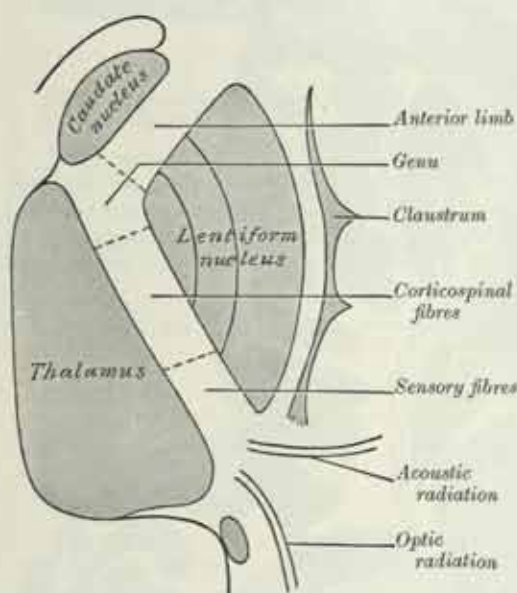
cerebellar hemisphere of the opposite side; (2) *thalamocortical fibres*, which arise, for the most part, in the anterior and medial nuclei of the thalamus and proceed to the frontal area and the gyrus cinguli.

The *genu*, *posterior limb* and *sublentiform part* contain: (1) the *great motor pathway* (corticospinal and corticonuclear fibres), part of which arises from the large pyramidal cells of the motor area. These fibres occupy the genu and rather more than the anterior half of the posterior limb. Experimental work has shown that the fibres are grouped in a definite manner in the internal capsule. The eyes, head, mouth, tongue and larynx are represented in the genu and adjoining part of the posterior limb; posterior to these are the fibres which represent the neck, upper limb, trunk and lower limb, in that order.

(2) *Thalamocortical fibres*, which arise in the lateral part of the thalamus and traverse the posterior limb to reach the corona radiata and, subsequently, the postcentral gyrus, the parietal association area and the motor and premotor areas. Many of these fibres are intermingled with the motor fibres, but others occupy a more posterior position.

(3) *Temporopontine fibres*, which arise in the cortex of the temporal lobe and are relayed in the nuclei pontis to the opposite side of the cerebellum.

FIG. 906.—Scheme showing the different parts of the internal capsule.



(4) *Fibres of the acoustic radiation*, which arise in the medial geniculate body and traverse the posterior part of the internal capsule. They sweep laterally and forwards, below and behind the lentiform nucleus, to gain the audiosensory area.

(5) *Fibres of the optic radiation*, which arise in the lateral geniculate body and sweep backwards from the posterior part of the internal capsule, to reach the visuosensory area. In their course they are intimately related to the posterior horn of the ventricle and are only separated from it by the tapetum (fig. 905). Some of the fibres of the optic radiation are corticofugal and are destined for the superior colliculus, from which they are relayed in the tecto-bulbar and tecto-spinal tracts (p. 997).

(6) *Corticothalamic fibres* are discussed on p. 1004.

THE BASAL NUCLEI

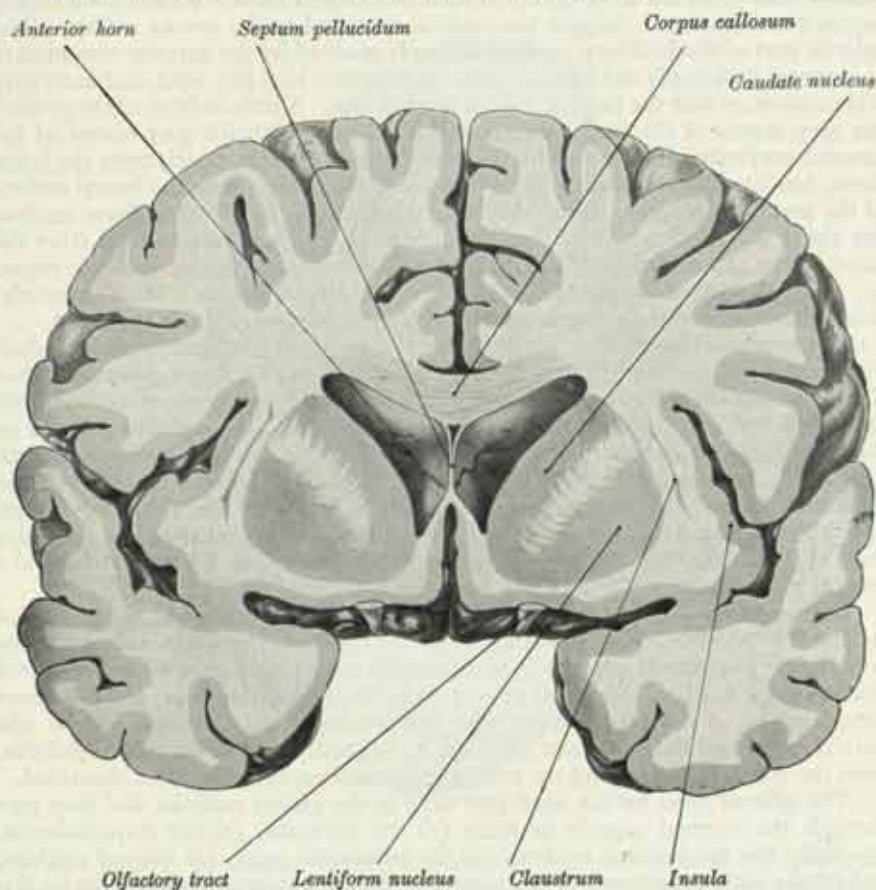
The **basal nuclei** include those subcortical masses of grey matter which are found within the cerebral hemisphere. They comprise the corpus striatum, incompletely subdivided into the lentiform and the caudate nuclei, the amygdaloid body and the claustrum.

The **corpus striatum** is a mass of grey matter which develops in the ventral part of the primitive hemisphere in the area immediately adjoining the inter-ventricular foramen. It is therefore not far distant from that part of the lateral wall of the diencephalon which gives rise to the thalamus. At first the corpus striatum is separated from the thalamus by a deep groove on the surface of the brain, but as the two masses enlarge, the groove is filled out. The thalamus and the corpus striatum therefore come into close contact with each other. When the projection fibres develop (p. 142) they cut into the corpus striatum and, save in its most anterior part, separate it into a lateral part, the lentiform nucleus, and a medial part, the caudate nucleus. The cleft so formed passes through the corpus striatum obliquely

so that the projection fibres of the internal capsule separate the lentiform nucleus completely from the thalamus.

The **caudate nucleus** is an arcuate mass of grey matter, which has already been seen in the floor of the anterior horn and body of the lateral ventricle and in the roof of the inferior horn. Its massive, rounded *head* projects into the anterior horn, forming the greater part of its floor. This surface is covered with ependyma, and is related above to the corpus callosum. Laterally it is separated from the lentiform nucleus by the anterior limb of the internal capsule, but this separation is complete only in its upper part. Below, the lateral aspect of the head is directly continuous with the putamen of the lentiform nucleus, and just above this strands of grey matter traverse

FIG. 907.—A coronal section through the anterior horns of the lateral ventricles.



the internal capsule and connect the two nuclei to each other (fig. 907). The striped appearance which this region presents gave origin to the term corpus striatum. Superiorly the margin of the head is related to the fronto-occipital arcuate bundle (p. 1061) and to the subcallosal fasciculus (pp. 1066 and 1076). Posteriorly the head rapidly diminishes in bulk and becomes continuous with the body of the nucleus, which lies in the lateral part of the floor of the lateral ventricle.

The *body* arches upwards, backwards and laterally. Its medial aspect is covered with ependyma and related to the thalamostriate vein, the stria terminalis and the thalamus. Laterally it is related to the fronto-occipital bundle above, and to the corona radiata below. Posteriorly it turns downwards at the posterior extremity of the thalamus and becomes continuous with the tail.

The *tail* of the caudate nucleus runs forwards in the roof of the inferior horn of the lateral ventricle, with the stria terminalis to its medial side (fig. 895). As the body curves downwards and forwards into the tail it passes below the corona radiata, the globus pallidus of the lentiform nucleus and the ansa lenticularis (p. 1009).

Anteriorly the tail of the caudate nucleus is continuous with the amygdaloid body in the roof of the inferior horn.

The **lentiform nucleus** is shaped like a biconvex lens, but the curvature of its medial surface is sharper than the curvature of its lateral surface. Cut on section, it is seen to consist of two portions, which differ from each other in their colour. The larger lateral portion, which is dark in colour, is termed the *putamen*; the smaller medial portion is of a lighter tint, and is termed the *globus pallidus*.

The lentiform nucleus is completely buried in the substance of the hemisphere. Laterally it is covered by a thin layer of white matter which constitutes the *external capsule*. This sheet is covered on its lateral side by the *claustrum*, which intervenes between it and the subcortical white matter of the insula. Medially the lentiform nucleus is in relation to the internal capsule, which separates it from the thalamus behind, and from the head of the caudate nucleus in front. Round its anterior, superior and posterior margins the nucleus is related to the corona radiata. The inferior part of the lentiform nucleus is deeply grooved by the anterior commissure as it passes backwards and laterally into the temporal lobe (fig. 896), and anteriorly it is continuous with the head of the caudate nucleus. A little in front of the groove, the grey matter of the corpus striatum is continuous with the grey matter of the anterior perforated substance, and the lateral striate arteries, which enter the brain there, run laterally and then turn upwards, in close contact with the lateral surface of the lentiform nucleus, before they pierce its substance. The lentiform nucleus lies above the inferior horn of the lateral ventricle and is separated from it by the fibres of the external capsule as they pass medially towards the subthalamic region (p. 1069), the tail of the caudate nucleus and the stria terminalis. More anteriorly, it is separated from the amygdaloid body by the *ansa peduncularis* (p. 1003).

Structure.—The caudate nucleus and the putamen are very similar in their histological features, and both differ very conspicuously from the globus pallidus. Their constituent nerve-cells are small and they show a poverty of nerve-fibres, those that are present forming a finely medullated plexus. The globus pallidus on the other hand is characterised by the possession of large cells, not unlike the motor cells of the anterior grey column of the spinal medulla. In addition, it is rich in medullated fibres, which are visible to the unaided eye where they form the external and internal medullary laminae. The external lamina separates the globus pallidus from the putamen, and the internal lamina subdivides it into a larger lateral and a smaller medial portion (fig. 908).

Connexions.—Available evidence concerning the *afferent fibres* to the corpus striatum is scanty. Thalamostriate and corticostriate fibres are now generally accepted. The use of physiological neuronography (p. 1040) has demonstrated that *areas* 4^r, 8, 2, 19 and 24 all project on to the caudate nucleus, and the fibres concerned lie in intimate relation with the fronto-occipital arcuate bundle and have been termed the *subcallosal fasciculus*.^{*} Afferent fibres to the globus pallidus, from the substantia nigra and the subthalamic nucleus, have also been described.

The *efferent fibres* for the most part arise in the globus pallidus, and they pass through the internal capsule to reach (1) the thalamus, (2) the hypothalamus, especially the subthalamic nucleus, (3) the substantia nigra, (4) the red nucleus, and (5) the olivary nucleus.† They possess medullated sheaths, but they can be distinguished from the fibres of the internal capsule by their smaller size. Most of these fibres appear on the inferior aspect of the globus pallidus and pass medially, constituting the *ansa lenticularis*. In addition, efferent fibres from the caudate nucleus to the substantia nigra have been described for man,‡ and it has been suggested that other fibres descend to the reticular formation of the pons and the medulla oblongata (p. 954).

Internuncial fibres connect the caudate nucleus and the putamen to each other and to the globus pallidus. They are finely medullated, and in the globus pallidus are responsible for the medullary laminae.

Functional significance of the corpus striatum.—The *palaeostriatum* of fishes, which corresponds to the globus pallidus in man, receives its afferent fibres from the olfactory pathways, and its efferent fibres establish connexions with the motor centres in the brain-stem and the spinal medulla. The view, however, that

* F. A. Mettler, *Res. Publ. Ass. nerv. ment. Dis.*, 21, 1942.

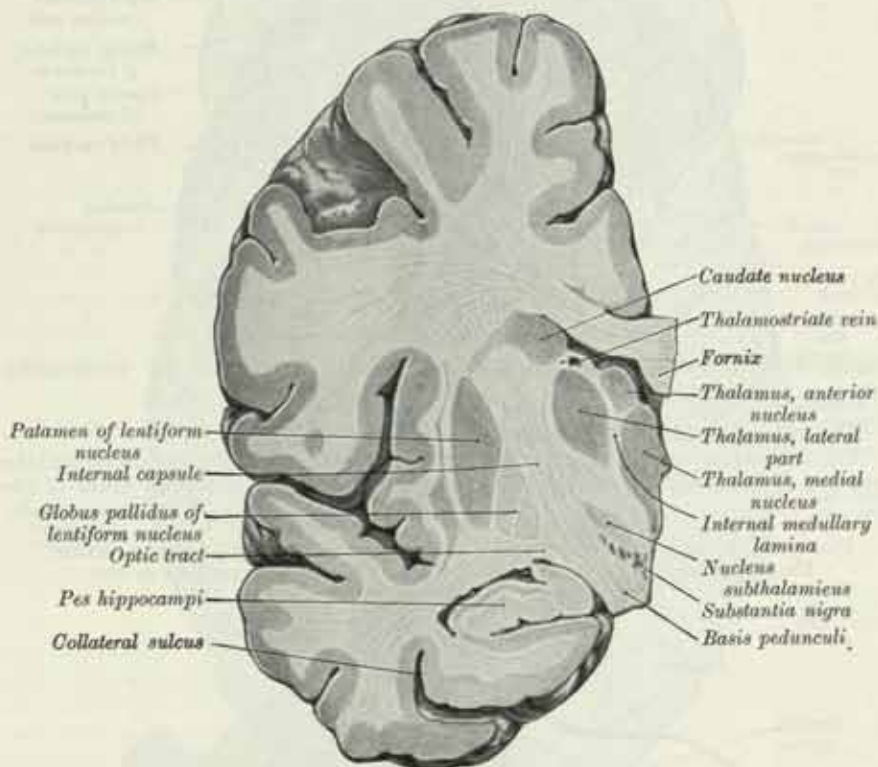
† See S. W. and M. Ranson, *Anat. Rec.*, 79, Suppl. 1941.

‡ H. W. Magoun, *Physiol. Rev.*, 50, 1950.

it functions as the highest motor centre in these animals is not supported by any direct, experimental evidence and its precise significance remains uncertain. The addition of the neostriatum in the reptilian brain is, as has been seen (p. 1020), synchronous with the passage into the telencephalon of new fibres of thalamic origin, and it has been suggested that, owing to the presence of the neostriatum and its connexions with both the thalamus and the palæostriatum, visual, tactile and other impressions are able to inhibit or modify the responses which would otherwise result from olfactory stimuli.

It is clear that the evolution of the neopallium and the process of telencephalisation have relegated the corpus striatum to a subsidiary role and that in man its

FIG. 908.—A coronal section through the right cerebral hemisphere. Anterior aspect.



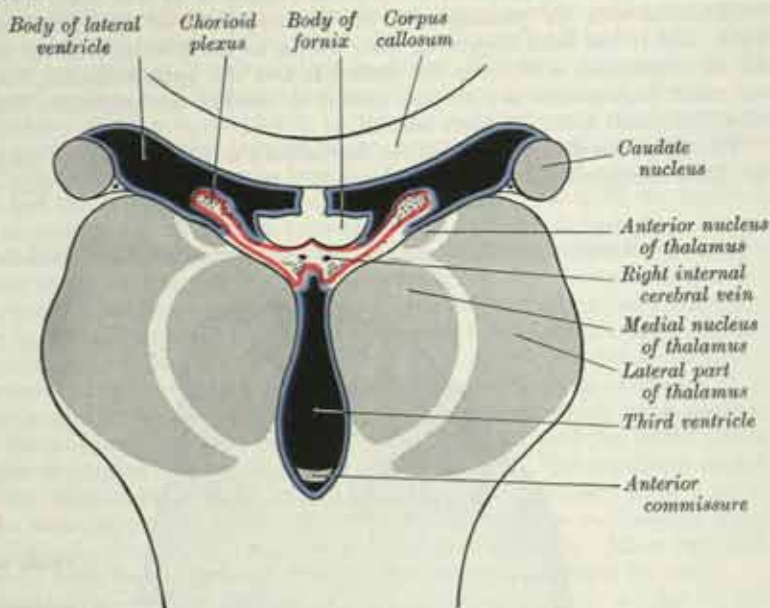
activities tend to be masked by the dominance of the motor area of the cortex. It is generally regarded as the source of an accessory motor pathway which establishes connexions with the motor nuclei and the spinal medulla either through subsidiary nuclei or through a series of relays in the reticular formation. This pathway forms an important part of the *extrapyramidal system* (p. 1076).

Despite the intimate relationship of the corpus striatum to the insula, no fibre connexions have been shown to exist between them.

Electrical stimulation of the caudate nucleus produces no obvious result in the quiescent animal, but if it is applied during movements, initiated by stimulation of the cerebral cortex or otherwise, the movements are at once inhibited.* Other experimental evidence is largely of a negative, and often contradictory, character. Ramsay Hunt, Kinnier Wilson and others have investigated cases of degeneration and atrophy of the corpus striatum. Rigidity, which is due to hypertonicity, and tremor, which is independent of the rigidity, are constant features, whether the neostriatum or the globus pallidus is affected. Ramsay Hunt finds that automatic associated movements, which involve mass muscular reactions, are lost when the globus pallidus is involved and that they are increased and accompanied by

* F. A. and C. C. Mettler, *Anat. Rec.*, 79, Suppl. 1941.

FIG. 909.—A coronal section through the lateral and third ventricles. Diagrammatic. The pia mater of the tela chorioidea is shown in red and the ependyma in blue.

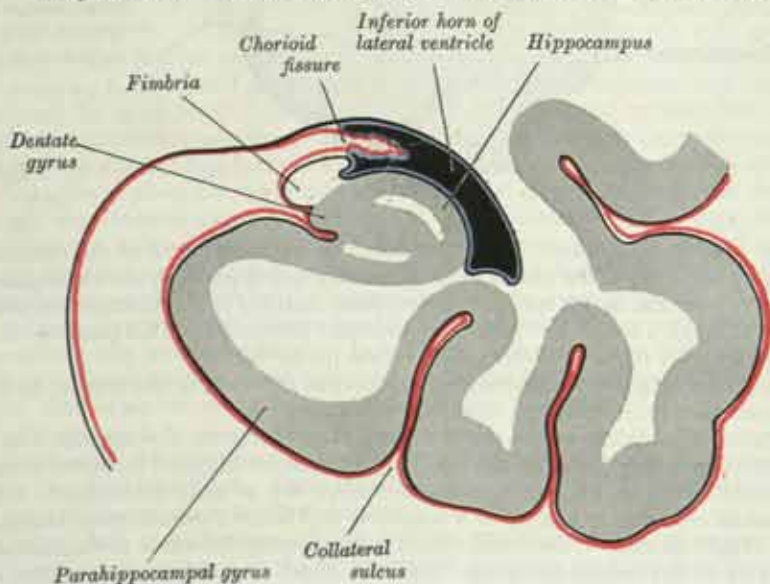


uncontrolled athetoid* movements when the disease affects the neostriatum only.

The **amygdaloid body** is described on p. 1033.

The **claustrum** is a thin sheet of grey matter, co-extensive with the insula and the putamen of the lentiform nucleus, from which it is separated by the fibres of the

FIG. 910.—A coronal section through the inferior horn of the lateral ventricle. Diagrammatic. The pia mater is shown in red and the ependyma in blue.



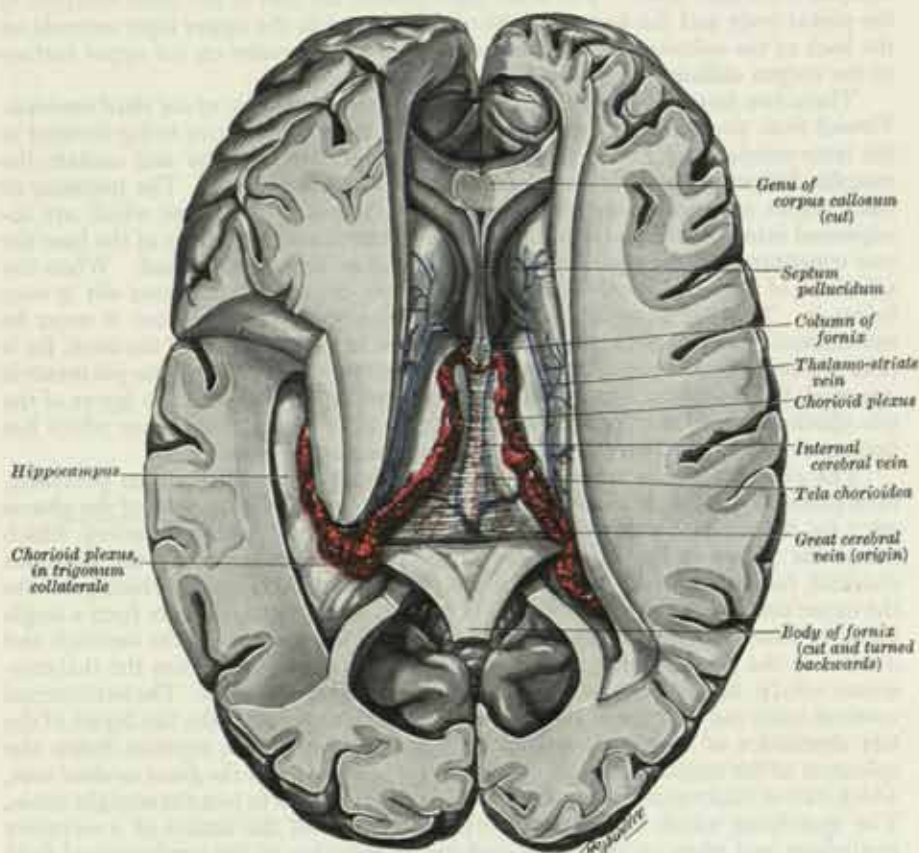
external capsule. It is thickest below and in front, where it becomes continuous with the anterior perforated substance. Regarded by some authorities as belonging to the

* The term 'athetoid movements' is used to describe repeated, deliberate movements of a purposeless character.

corpus striatum and by others as a detached portion of the insular cortex, it is undoubtedly of cortical origin, but its connexions and functions are quite unknown.

The **external capsule** is a thin layer of white matter which is interposed between the lateral aspect of the lentiform nucleus and the claustrum. According to Meynert the fibres of the external capsule are derived from the frontoparietal operculum of the insula and, after passing across the lateral surface of the lentiform nucleus, they turn medially below the nucleus and the ansa lenticularis. Their subthalamic connexions are uncertain. Some of the fibres of the anterior commissure are believed to traverse the external capsule.

FIG. 911.—The tela chorioidea of the third ventricle and the chorioid plexus of the lateral ventricle.



The trunk of the corpus callosum has been removed and the body of the fornix has been cut across anteriorly and turned backwards.

The chorioid fissure and the chorioid plexus of the lateral ventricle.—The *chorioid plexus* of the lateral ventricle is a highly vascular fringe of pia mater which projects into the ventricular cavity, invaginating the ependymal medial wall of the ventricle before it and receiving from it a complete investment (fig. 909). It extends as far forwards as the interventricular foramen, where it is continuous with the corresponding plexus of the opposite side. Posteriorly it is carried round the posterior end of the thalamus into the inferior horn as far as the pes hippocampi. The ependyma which covers the chorioid plexus is an infolded part of the medial wall of the hemisphere, and this infolding constitutes the *chorioid fissure*. The lips of the fissure are the lateral edge of the fornix and the upper surface of the thalamus, in the central part of the ventricle (fig. 909), and the edge of the fimbria and the stria terminalis in the inferior horn (fig. 910). The two parts of the fissure are directly continuous with each other round the posterior end of the thalamus. It will be remembered that the chorioid fissure is the first fissure to appear on the surface of

the hemisphere (p. 139), and coronal sections across the brain of a two-months' embryo show that the floor of the upper part of the fissure is directly continuous with the ependymal roof of the third ventricle, and that the vascular pia mater which covers the latter is continued into the chorioid fissure on each side. At this stage, and prior to the development of the commissures and the expansion of the lamina terminalis, only one layer of pia mater covers the roof of the third ventricle (fig. 149, A). When the corpus callosum grows backwards, it passes above the line of the chorioid fissure and carries with it on its under surface a second layer of pia mater (fig. 870). In this way two layers of pia mater come to lie above the ependymal roof of the third ventricle and on each side they pass into the chorioid fissure to enclose the vessels of the chorioid plexus (fig. 909). Posteriorly these two layers separate from each other. The lower layer follows the roof of the third ventricle to the pineal body and the tectum of the mid-brain, while the upper layer ascends on the back of the splenium and is continuous with the pia mater on the upper surface of the corpus callosum (fig. 870).

These two layers of pia mater constitute the *tela chorioidea of the third ventricle*. Viewed from above, they form a triangular fold, the rounded apex being situated at the interventricular foramen (fig. 911). The edges are irregular and contain the vascular fringes of the chorioid plexuses of the lateral ventricles. The posterior or basal angles are continuous with the vascular fringes of pia mater which are invaginated into the inferior horns, but over the central and wider part of the base the two constituent layers separate from each other as already explained. When the splenium of the corpus callosum is viewed from behind, a transverse slit is seen below it. This slit is termed the *transverse fissure of the brain*, but it must be remembered that it is not really a cerebral fissure in the true sense of the term, for it does not correspond to any infolding of the cerebral cortex. Before the pia mater is removed, the transverse fissure leads into the interval between the two layers of the tela chorioidea, and this interval is a portion of the extra-cerebral space which has been enclosed by the backward growth of the corpus callosum.

The chorioid plexus consists of minute and highly vascular villous processes, each possessing an afferent and an efferent blood-vessel. The *arteries* of the plexus are: (a) the anterior chorioid artery, a branch of the internal carotid artery, which enters the plexus at the anterior end of the inferior horn; and (b) the posterior chorioid, one or two small branches of the posterior cerebral artery, which pass into the upper part of the chorioid fissure. The *veins* of the plexus unite to form a single tortuous vessel (chorioid vein) which begins in the inferior horn of the ventricle and courses in the plexus to the interventricular foramen and there joins the thalamostriate vein (p. 840) to form the corresponding *internal cerebral vein*. The two internal cerebral veins run backwards close to the median plane between the two layers of the tela chorioidea of the third ventricle. When the two layers separate below the splenium of the corpus callosum, the two veins unite to form the *great cerebral vein*, which curves backwards and upwards behind the splenium to join the straight sinus. The ependyma which covers the chorioid plexus is of the nature of a secretory epithelium and plays an important part in the secretion of the cerebrospinal fluid (p. 1085).

The weight of the brain.—The average weight of the brain, in the adult male, is about 1380 gms.; that of the female, about 1250 gms. In the male, the maximum weight out of 278 cases was 1840 gms. and the minimum weight 964 gms. The maximum weight of the adult female brain, out of 191 cases, was 1585 gms. and the minimum weight 879 gms. The brain increases rapidly during the first twelve months of life, and the brain of a year-old child is on the average two and a half times as heavy as the brain of a newly-born infant (p. 143). By the sixth year the brain has reached 85 per cent. or more of its weight in the adult. This increase is attributable for the most part to the medullation of the nerve-fibres. As age advances, the brain decreases slowly in weight; in old age the decrease takes place more rapidly.

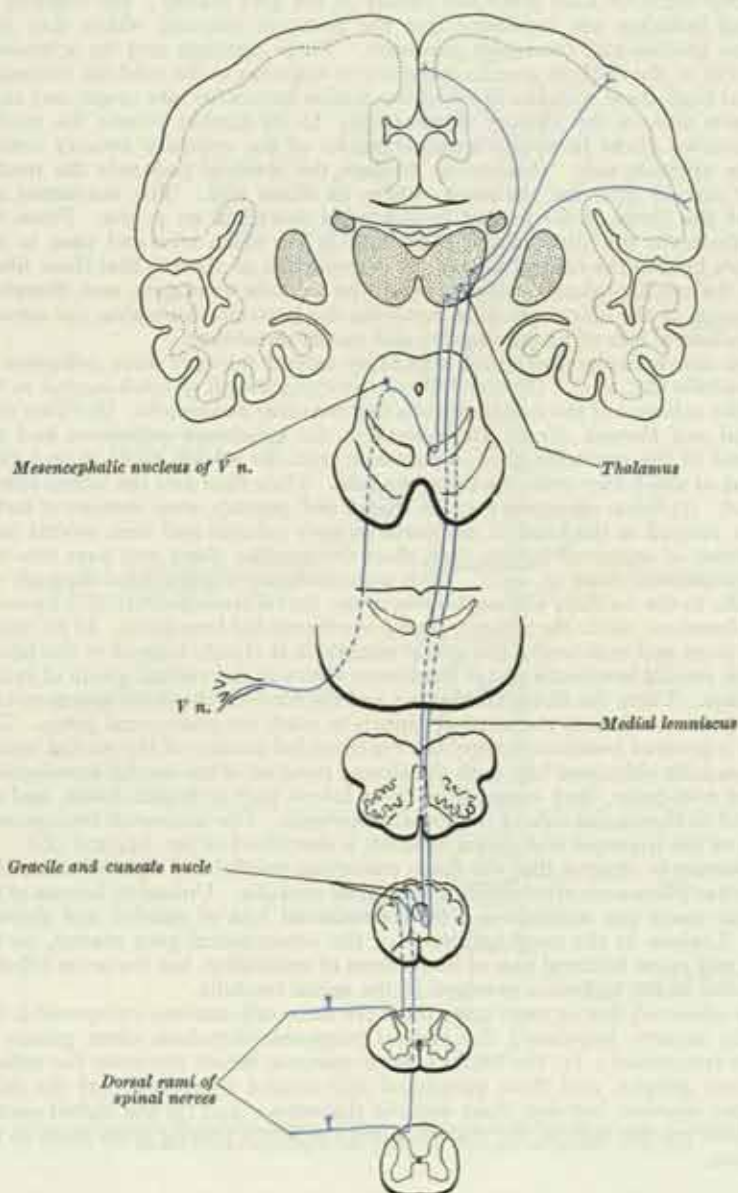
Applied Anatomy.—The *internal capsule* is often the seat of hæmorrhage from the lateral striate artery (Charcot's 'artery of cerebral hæmorrhage'), or of thrombosis, in patients whose vessels are weakened by old age or disease. A 'stroke,' or 'apoplexy,' is the result; blood is effused from the ruptured vessels and tears up the surrounding brain tissue, and also interferes with the neighbouring fibres by the compression set up by its mass. If the hæmorrhage is sudden and at all large, rapid and complete loss of consciousness follows, with paralysis of the opposite

side of the body and loss of control over the sphincters, together with a variable degree of hemianæsthesia. If it is the posterior limb of the internal capsule that is involved, the paralysis will be more marked in the leg than in the arm, and will be associated with homonymous hemianopia or blindness of the corresponding halves of the two retinae, the patient being unable to see objects on the opposite side of the body.

THE CHIEF NERVE TRACTS

The anatomy of the various parts of the central nervous system having been described in detail, a short summary will now be given of the chief ascending and

FIG. 912.—The pathway of the fibres conveying some tactile and conscious proprioceptive sensibility.



The proprioceptive pathway for the trigeminal nerve is still uncertain.

descending nerve tracts connecting the brain and the spinal medulla. This may be effected most conveniently by grouping them as follows: (a) the sensory (ascending) tracts, (b) the motor (descending) tracts, and (c) the cerebellar systems (ascending and descending).

THE SENSORY TRACTS

The **sensory impulses** traversing the cerebrospinal axis may be resolved into the following groups: (1) *interoceptive*, arising in the viscera; (2) *proprioceptive*, arising in the muscles, tendons, joints, etc.; and (3) *exteroceptive*, initiated on the surface of the body.

(1) Little is known concerning the pathway followed by the interoceptive fibres. (2) The proprioceptive fibres are accompanied throughout by the fibres which convey tactile sensibility (light touch). They enter the spinal medulla through the posterior roots of the spinal nerves, and at once divide into descending and ascending branches; the descending branches soon enter and ramify in the grey matter; the majority of the ascending branches are continued into the posterior funiculi, where they join the fasciculus gracilis and fasciculus cuneatus. These fasciculi end by arborising around the cells of the nucleus gracilis and nucleus cuneatus in the medulla oblongata (fig. 912), and from these cells the fibres of the medial lemniscus take origin and cross to the opposite side in the sensory decussation. In its further course the medial lemniscus receives fibres from the terminal nuclei of the ordinary sensory cranial nerves of the opposite side. Ascending through the cerebral peduncle the medial lemniscus is carried into the thalamus, where its fibres end. The laminated arrangement of the fibres of the medial lemniscus is described on p. 962. From the cells of the thalamus the fibres of the third link in the chain arise and pass to the cerebral cortex behind the central sulcus. It is important to observe that these fibres do not cross the median plane until they reach the medulla oblongata, and, therefore unilateral lesions of the spinal medulla involving the posterior funiculus, are accompanied by *ipsilateral* loss of proprioceptive and tactile sensibility.

(3) Fibres conveying exteroceptive sensibility ascend through three pathways in the spinal medulla (fig. 913). (a) Some fibres conveying stimuli of touch ascend in the posterior white columns of the spinal medulla (see preceding paragraph). (b) Fibres conveying painful and thermal stimuli are relayed in the substantia gelatinosa and the adjoining head of the posterior grey column and cross the median plane at or a little above the level at which they enter the spinal medulla. They then join the lateral spinothalamic tract. (c) Fibres conveying pressure stimuli and, possibly, some elements of tactile sensibility are relayed in the head of the posterior grey column and then ascend for a varying number of segments before they cross the median plane and pass into the anterior spinothalamic tract (p. 941). Both spinothalamic tracts ascend through the spinal medulla to the medulla oblongata, where the lateral tract is continued upwards as the *spinal lemniscus*, while the anterior tract joins the medial lemniscus. In its course through the pons and mid-brain, the spinal lemniscus is closely related to the lateral portion of the medial lemniscus and it terminates above in the ventral group of nuclei of the thalamus. There the fibres are relayed and the fibres of the third neurones pass through the posterior limb of the internal capsule to reach the postcentral gyrus. The fibres of the *trigeminal lemniscus* occupy the ventrimedial portion of the medial lemniscus in the medulla oblongata but, with the altered position of the medial lemniscus in the pons and mid-brain, they come to lie in its lateral part at higher levels, and are closely related to the medial side of the spinal lemniscus. The laminated arrangement of the fibres of the trigeminal and spinal lemnisci is described on pp. 944 and 969.

It is important to observe that the fibres conveying painful and thermal sensations cross the median plane soon after entering the spinal medulla. Unilateral lesions of the spinothalamic tracts are accompanied by contralateral loss of painful and thermal sensibility. Lesions in the neighbourhood of the commissural grey matter, on the other hand, will cause bilateral loss of both forms of sensibility, but the areas affected will correspond to the segments involved in the spinal medulla.

It will be observed that in most cases there are three cell-stations interposed in the course of the sensory impulses; for clinical purposes, therefore, three groups of neurones are recognised: (1) the *lowest sensory neurones*, which comprise the cells of the dorsal root ganglia, and their peripheral and central processes; (2) the *intermediate sensory neurones* between these and the thalamus; and (3) the *highest sensory neurones*, which are the cells of the thalamus and the fibres passing from them to the cerebral cortex.

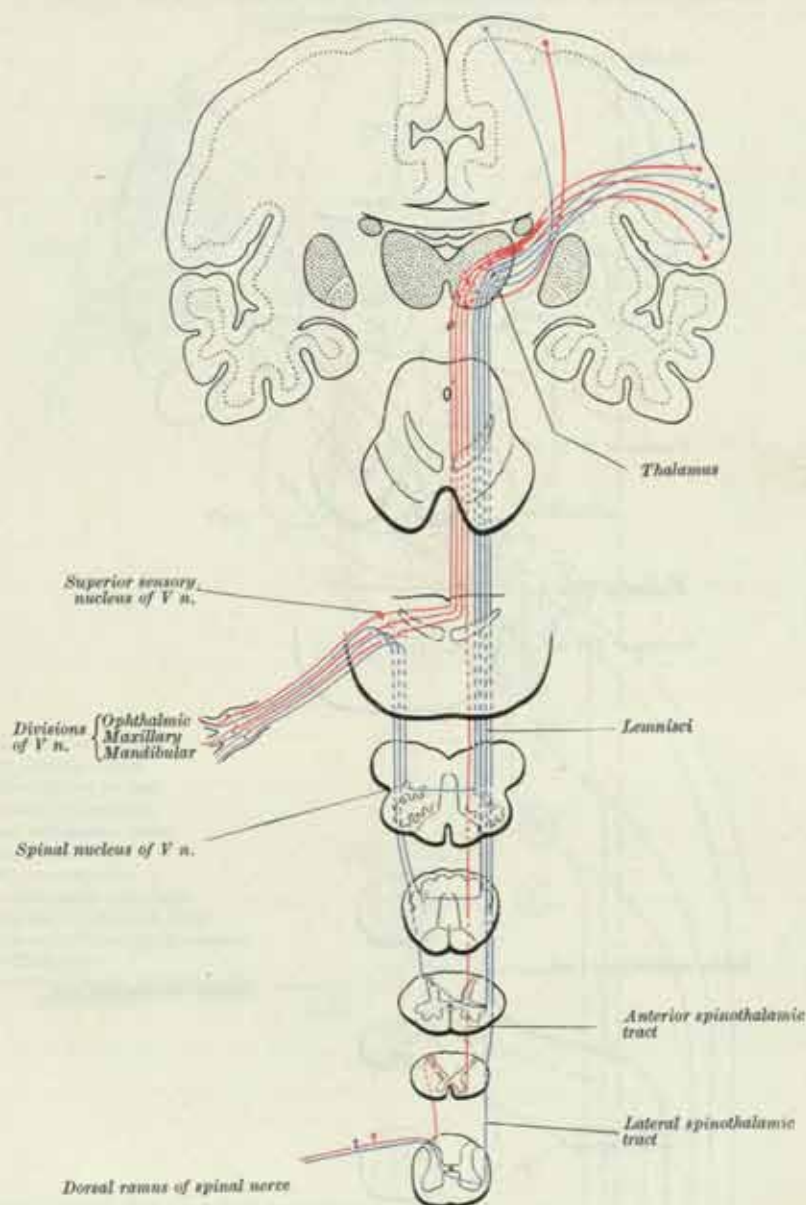
THE MOTOR TRACTS

Included under this heading are (a) the corticospinal and corticonuclear and (b) the extrapyramidal tracts.

The corticospinal and corticonuclear system (fig. 914).—The constituent

fibres of this system are the axis-cylinder processes of the large pyramidal cells situated in the ganglionic layer and other cells of the motor area of the cortex (p. 1037). The fibres converge as they descend through the corona radiata, and pass between the

FIG. 913.—The pathways for fibres conveying exteroceptive sensibilities.
(Blue = pain and thermal. Red = tactile.)

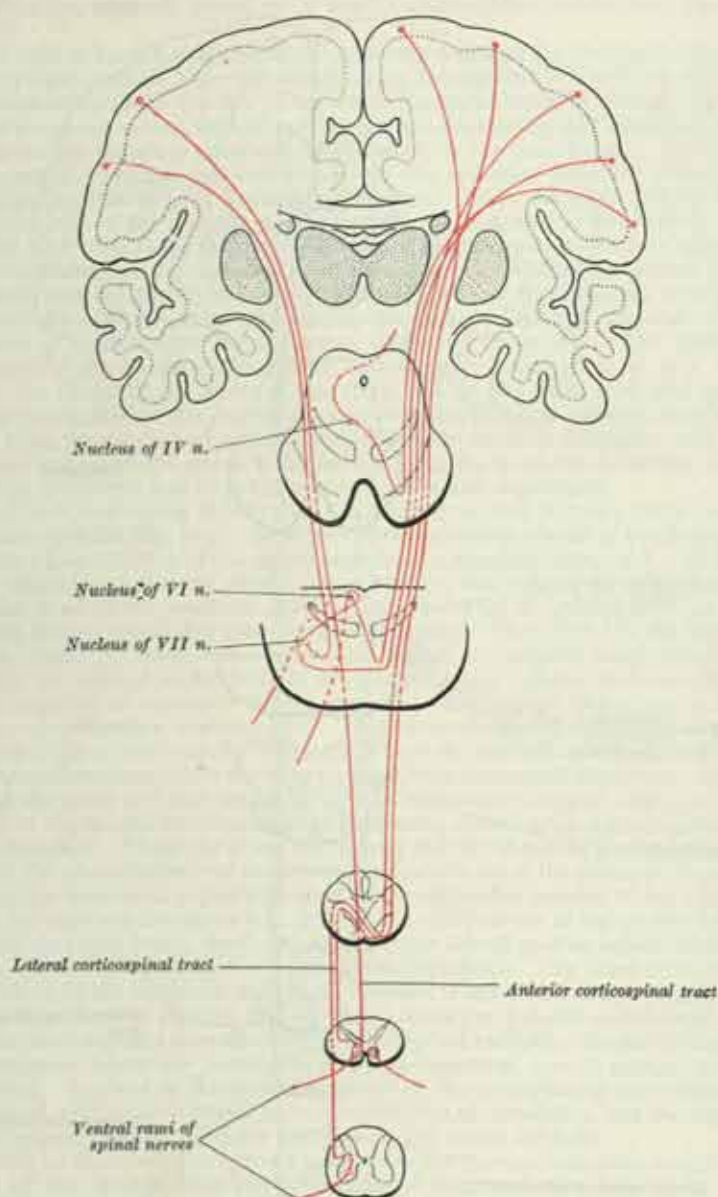


The course of the fibres from the anterior spinothalamic tract in the brain-stem is uncertain. The tactile fibres travelling in the posterior funiculus are shown in fig. 912.

lentiform nucleus and thalamus, in the genu and in the anterior two-thirds of the posterior limb of the internal capsule; those in the genu are named the corticonuclear (geniculate) fibres, the others the corticospinal fibres. Both sets of fibres proceed downwards, through the middle three-fifths of the base of the cerebral peduncle, and

then the corticonuclear fibres cross the median plane, and end by arborising around the cells of the motor nuclei of the cranial nerves. The corticospinal fibres are continued downwards into the pyramid of the medulla oblongata, and thence proceed by two

FIG. 914.—The principal motor pathways.

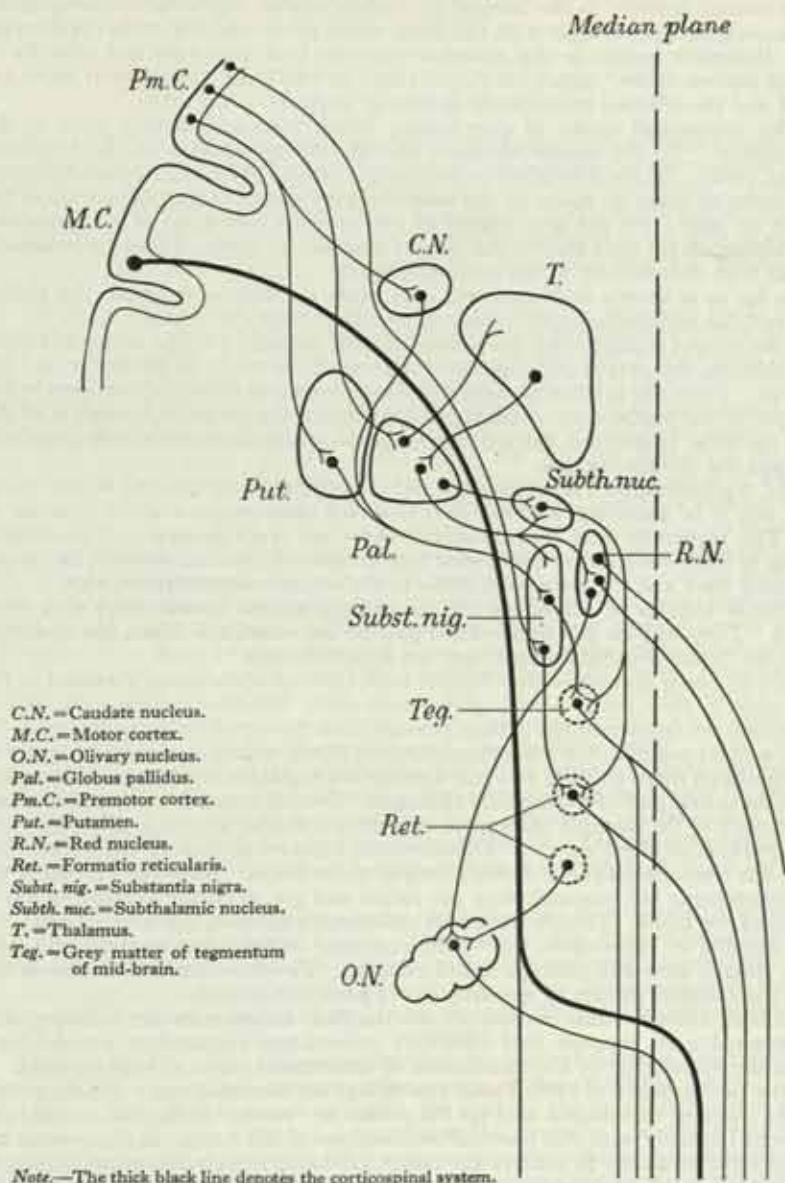


Note that the anterior corticospinal tract is variable in its extent and does not reach the lower end of the spinal medulla.

paths. The fibres nearest to the anterior median fissure cross the median plane, intersecting the corresponding fibres from the opposite side and forming the *decussation of the pyramids*, and descend in the lateral funiculus of the opposite side of the spinal medulla, as the lateral corticospinal fasciculus (crossed pyramidal tract). Throughout

the length of the spinal medulla, fibres from this tract pass into the grey matter, to end by arborising with the dendrites and cyton of an internuncial neurone at the base of the posterior column which sends its axon to synapse with cells of the anterior column. The more laterally placed corticospinal fibres do not decussate in the medulla oblongata, but descend as the anterior corticospinal fasciculus (direct pyramidal tract); in each segment of the upper half of the spinal medulla some of these fibres cross in the anterior white commissure, with the result that all end in the grey matter of the oppo-

FIG. 915.—Diagram showing the principal components of the extrapyramidal system. (After Denny-Brown.)



site side. There is considerable variation in the extent to which decussation takes place in the medulla oblongata; about two-thirds or three-fourths of the corticospinal fibres usually decussate in the medulla oblongata and the remainder in the spinal medulla. Recent experimental evidence has shown that in addition corticospinal fibres descend uncrossed in the lateral funiculus of the same side. Most, if not all, of these fibres, many of which can be traced as low as the mid-sacral region, are believed to terminate, through the medium of a connector neurone, by arborising around cells in the ipsilateral anterior grey column.

The Extrapyrarnidal System * (fig. 915).—The constituents of the extrapyramidal system comprise (a) the premotor, and possibly other areas of the cortex, (b) a number of subcortical nuclei of grey matter and (c) the fibre pathways which link them to one another and to the motor nuclei of the brain-stem and spinal medulla.

(a) The *premotor area* is, presumably, linked to the motor area by a very large number of short arcuate fibres, and it projects on to the corpus striatum, the globus pallidus, and the substantia nigra. The corticostriate fibres have been identified † as a bundle, termed the *subcallosal fasciculus*, which extends dorsally along the upper border of the head and body of the caudate nucleus lying below the corpus callosum and intimately related to the fronto-occipital arcuate bundle. These fibres are related laterally to the base of the corona radiata, while the cortico-pallidal and cortico-nigral fibres mingle with the fibres of the pyramidal system in the internal capsule. Extensive lesions in this situation interrupt both pathways and give rise to the typical picture of the 'upper neurone lesion,' in which the contralateral limbs are paralysed and the affected muscles are spastic or hypertonic (*see later*).

(b) The subcortical nuclei of grey matter which form constituent parts of the system include: (1) the corpus striatum and the globus pallidus of the lentiform nucleus (p. 1064); (2) the subthalamic nucleus (p. 1009); (3) the red nucleus (p. 992); (4) the substantia nigra (p. 990); (5) the scattered grey matter of the tegmentum of the mid-brain (p. 990); (6) the grey matter of the reticular formation of the pons and medulla oblongata (p. 954) and (7) the olivary nucleus (p. 956). These have already been dealt with individually in the preceding pages.

(c) So far as is known at the present time, only the corpus striatum, the globus pallidus and the substantia nigra receive fibres direct from the cortex.

Both the corpus striatum and the globus pallidus project on to the substantia nigra and, in addition, the globus pallidus sends efferent fibres to the subthalamic and the red nucleus. From the substantia nigra and these two nuclei efferent fibres pass to the grey matter of the tegmentum of the mid-brain and of the reticular formation of the pons and medulla. In addition, the red nucleus projects directly on to the spinal medulla (p. 993) and the olivary nucleus.

Finally, tegmento-spinal, reticulospinal and olivospinal fibres descend to the spinal medulla, but it is uncertain whether they descend uninterrupted or by a series of relays. The tegmento- and reticulo-spinal fibres are both crossed and uncrossed. According to some authorities, the crossed reticulospinal fibres run down in the lateral corticospinal tract and the uncrossed fibres in the anterior corticospinal tract.

Additional sources of activation for the extrapyramidal system have also been described. They include the small-celled part of the substantia nigra, the thalamus (through the thalamo-pallidal fibres) and the hypothalamus.

It must be noted that while the fibres of both systems are intimately related in the internal capsule, their paths diverge in the brain-stem. The fibres of the corticospinal system, which are uninterrupted in their passage from the cortex to the spinal medulla, occupy a ventral position, but the extrapyramidal fibres, which descend by a series of relays, are placed more dorsally and run through the tegmentum of the mid-brain and pons and the dorsal part of the medulla oblongata. On this account, in lesions confined to the pyramid of the medulla oblongata, only the pyramidal system is affected, while the extrapyramidal fibres escape. Experimental bilateral section of the pyramid in monkeys † is characterised by a *flaccid paralysis* of the limbs. Although certain of the grosser movements are retained, they are feeble and are rendered difficult owing to instability of the trunk. Deeply patterned emotional responses, e.g. fear, desire, etc., are still capable of expression, the 'body-righting' reflexes are retained and progression, though slow and clumsy, is still possible. The most striking feature of the lesion is the *complete absence of spasticity in the paralysed muscles*.

Since both systems must necessarily use the final common motor pathway, it is not unreasonable to suppose that voluntary movements initiated at cortical level represent the summation of the expressions of interrelated parts of both systems.

For the performance of skilled acts, two things are essential, viz.: (1) the power to execute discrete movements and (2) the power to 'weave' them into an effective sequence in harmony with the postural mechanisms of the body. Both systems are employed simultaneously to achieve the result, (1) being mainly the responsibility of the pyramidal system and (2) the responsibility of the extrapyramidal system. The numerous connexions and ramifications of the latter system enable it to exert a considerable influence over the postural mechanisms of the body. This influence is mainly inhibitory so that damage to the extrapyramidal system leads to a release of exaggerated postural tone.

*For a detailed review, consult D. Denny-Brown, *Oxford Loose-Leaf Medicine*, Oxf. Univ. Press, New York, 1945; and F. A. Mettler, *Res. Publ. Ass. Nerv. Ment. Dis.*, 21, 1942.

†S. S. Tower, *Brain*, 58, 1935, and 63, 1940.

Lesions of the extrapyramidal system are associated with various motor phenomena, such as tremor, hypertonia, spasms and other forms of hyperkinesia, but it is to be noted that the resulting movements are uncontrollable. It has been suggested that the underlying cause is disproportional innervation of reciprocating muscle groups.

The axons of the motor cells in the cranial nuclei proceed through the cranial nerves, while those of the cells in the anterior grey column of the spinal medulla pass out in the ventral roots of the spinal nerves, forming thus in each instance a *final common motor pathway*, along which impulses are conducted to the muscles of the head, trunk and limbs. For clinical purposes the neurones constituting the final motor pathway are grouped as the *lower motor neurones*, while the other neurones of the motor pathway form the group of *upper motor neurones*.

THE CEREBELLAR SYSTEMS

The cerebellum exercises such an important influence on muscle co-ordination (p. 982) that impulses must be able to reach it from all parts of the cerebral cortex as well as from the spinal medulla, while impulses are conveyed from it to other co-ordinating and motor nuclei in the cerebrospinal axis. The activities of the cerebellum are essential for the perfect execution of voluntary movements and skilled acts. It is therefore intimately associated with both the pyramidal and the extrapyramidal systems.

Afferent tracts.—A considerable number of afferent impulses reach the cerebellum by way of the spinal medulla through the medial fibres of the dorsal nerve-roots. In the spinal medulla there are three main pathways. The entering fibres, which may be collaterals of the long ascending fibres in the posterior funiculus or terminals and collaterals of the intermediate fibres (p. 942), may end around the cells of the dorsal nucleus; the fibres from these cells form the posterior spino-cerebellar tract of the same side, and are carried up to the medulla oblongata, where they enter the inferior cerebellar peduncle and are conveyed to the cortex of the vermis of the cerebellum. A second group of entering fibres arborises around the cells of the posterior grey column of the spinal medulla; of the fibres of these cells some cross to the opposite side while others pass up the same side, forming an anterior spino-cerebellar tract, which traverses the spinal medulla on the surface of the lateral white column, runs through the medulla oblongata and pons, and then turns downwards and backwards to reach the cortex of the superior vermis by way of the superior cerebellar peduncle. The third group of entering fibres runs up in the fasciculus cuneatus, and ends in the accessory cuneate nucleus; relayed there, the fibres (external arcuate, p. 958) pass in the inferior cerebellar peduncle to reach the cerebellar cortex.

Three important afferent tracts to the cerebellum run from the brain-stem, viz. the vestibulocerebellar, the olivocerebellar and the tectocerebellar. The vestibulocerebellar tract arises from the vestibular nuclei in the rhomboid fossa, and runs in the inferior cerebellar peduncle to end mainly in the flocculi and the nodule (p. 974). The olivocerebellar tract arises in the olivary nucleus, crosses the median plane, and gains the cerebellum through the inferior cerebellar peduncle. The tectocerebellar tract has its origin in the cells of the colliculi and enters the cerebellum through the superior cerebellar peduncle.

Of the remaining afferent fibres to the cerebellum the most important group is that of the cerebro-ponti-cerebellar tracts. These fibres arise from cells of the cerebral cortex, travel downwards through the internal capsule and cerebral peduncle, and end by arborising round the cells of the nuclei pontis. New fibres arise from the cells of these nuclei, cross the median plane, pass through the middle cerebellar peduncle, and end in the cortex of the cerebellar hemispheres.

Efferent tracts.—The efferent tracts from the cerebellar cortex originate from the Purkinje cells and run to arborise around cells of the cerebellar nuclei; with the exception of the flocculus and, possibly, the nodule, the cerebellar cortex sends no fibres direct to the rest of the brain or to the spinal medulla. Several small groups of fibres arising from the cerebellar nuclei run to various nuclei in the cerebrospinal axis, but the chief efferent tract is that which forms the greater part of the superior cerebellar peduncle, crosses the median plane, and ascends to the red nucleus, where some of its fibres terminate. Others reach the thalamus and thence are relayed to the premotor area (p. 1041). From the red nucleus the rubrospinal tract arises, crosses to the opposite side, and travels down in the pons and medulla oblongata to the lateral funiculus of the spinal medulla, where it ultimately ends around the motor cells in the anterior grey column. From what has already been stated it follows that, whereas the final common motor pathway is predominantly under the control of the contralateral cerebral hemisphere, it is to a similar extent controlled and regulated by the cerebellar hemisphere of the same side of the body. On this account extensive injury restricted

to one cerebellar hemisphere is associated with hypotonia of the limb muscles of the same side.

Other efferent fibres from the cerebellar nuclei pass to the nuclei of the vestibular nerve, and are relayed to the spinal medulla in the vestibulospinal tract and to the motor nuclei of the cranial nerves in the medial longitudinal bundle (p. 994). The fastigio-bulbar tract (p. 979), which takes origin in the nucleus fastigii, hooks round the lower end of the superior cerebellar peduncle, traverses the inferior peduncle and terminates in the reticular formation (p. 954) of the medulla oblongata and the pons.

MYELINATION OF THE FIBRE GROUPS OF THE SPINAL MEDULLA AND BRAIN-STEM

According to Lucas Keene and Hewer * the process of myelination in the spinal medulla and the brain-stem occurs in four distinct stages. During the fourteenth week of intrauterine life myelination commences in the ventral and dorsal roots of the spinal nerves, in all the cranial nerves (with the exceptions of the optic, the cochlear and the sensory part of the trigeminal nerve (p. 1100)) and in many of the tracts. Between the twenty-second and the twenty-fourth weeks additional fibre groups become affected. The process receives a fresh impetus at or just before birth and again about eight months later.

Depending on the number and on the length of the fibres involved, the period over which the process extends may last for from two to ten weeks or more.

The tracts become myelinated in the following order :

In the first period : (1) fasciculus cuneatus, (2) posterior spinocerebellar, (3) anterior spinocerebellar, (4) lateral spinothalamic, (5) spinotectal, (6) anterior intersegmental and (7) the medial longitudinal bundle.

In the second period : (1) fasciculus gracilis, (2) posterior intersegmental, (3) lateral intersegmental, (4) medial lemniscus, (5) olivocerebellar and (6) fasciculus retroflexus.

In the third period : (1) posterolateral, (2) lateral corticospinal (crossed pyramidal), (3) rubrospinal, (4) anterior corticospinal (direct pyramidal), (5) external arcuate fibres, (6) pontocerebellar fibres and (7) corticopontine fibres.

In the fourth period : the bulbospinal tract (p. 942).

Applied Anatomy.—The chief symptoms of diseases of the brain and spinal medulla depend upon the particular systems of neurones picked out for attack, and some of them may be briefly summarised as follows. *Motor paralysis* of the *spastic* type, with rigidity of the muscles and increased reflexes, follows destruction of the cerebrospinal fibres in the internal capsule. According to Fulton † spasticity does not occur unless the fibres from the premotor cortex are destroyed as well as the fibres from the motor cortex. In experiments on monkeys, spasticity is a feature of transections of the brain-stem above the level of the red nucleus, but does not occur when transections are made below that level. ‡ Further, cases of flaccid hemiplegia following thrombosis of the middle cerebral artery are on record. *Flaccid* paralysis, with loss of the reflexes and rapid muscular atrophy, follows destruction of the lower motor neurones. *Sensory paralysis* follows injury to any part of the sensory path; in tabes it is due to injury of the lowest sensory neurones, in hemiplegia to destruction of the highest sensory axon as it traverses the posterior limb of the internal capsule. *Dissociation of sensations*, or the loss of some forms of sensation while others remain unimpaired, is seen in a number of conditions such as tabes and syringomyelia; it shows that the paths through which various forms of sensation travel to the brain are different. *Abnormalities of reflex actions* are of very great help in the diagnosis of nervous complaints. The numerous *superficial or skin reflexes* (e.g. the plantar, in which tickling the sole of the foot brings on plantar flexion of the toes), if present, show that the reflex arcs on whose integrity their existence depends are intact; but they are often absent in health and so cannot be trusted to indicate disease. The *deep reflexes or tendon reactions*, such as the knee-jerk, or the tendo calcaneus jerk, are increased in chronic degeneration of, or gradually increasing pressure on, the corticospinal fibres (upper motor neurone). They are lost when the lower motor or lower sensory neurones are diseased, and in a few other conditions; absence of the knee-jerk is very rare in health, and suggests disease in some part of its reflex arc in the third and fourth lumbar segments of the medulla, or else, more rarely, grave intracranial or spinal disease cutting off the lower from the higher nervous centres. The *organic reflexes* of the pupil, bladder, and rectum are of the greatest practical importance. The commonest defect in the reflexes of the pupil is reflex iridoplegia, or failure to contract on exposure to light, without failure to contract on convergence or accommodation (*Argyll Robertson pupil*) (p. 1257). The pupil is also contracted, and may or may not dilate when the skin of the neck is pinched (the *cilio-spinal*

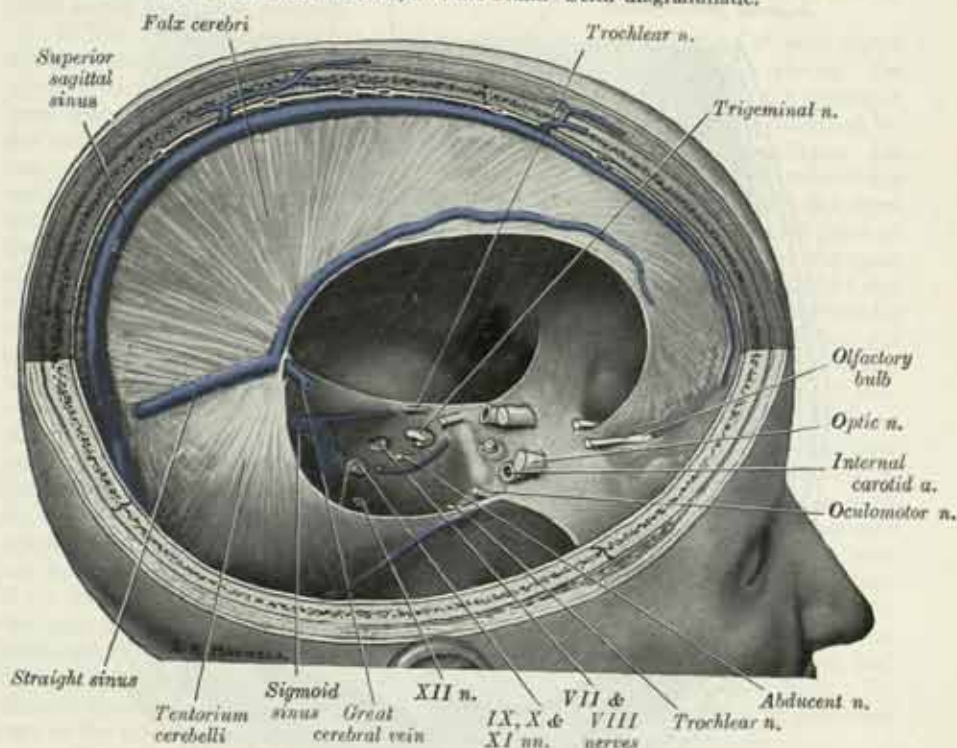
* M. F. Lucas Keene and E. E. Hewer, *J. Anat.*, Lond., **66**, 1931.

† J. F. Fulton, *Physiology of the Nervous System*, 3rd Ed. Oxford University Press, 1951.

‡ S. Tower, *Brain*, **63**, 1940.

reflex). Micturition is a spinal reflex much under the control of the cortex (p. 1041); if the centre for micturition in the second sacral segment is destroyed, the sphincter and the walls of the bladder are paralysed, the bladder becomes distended with urine, and incontinence from overflow results. If this centre escapes injury but is cut off more or less completely from impulses descending to it from above there will be more or less interference with micturition. This varies in degree from the 'precipitate micturition' of tabetic patients, who must perform hurry to pass water the moment the impulse seizes them, to the state of 'reflex incontinence,' when the bladder automatically empties itself periodically, almost without the patient's knowledge. Defecation is also a spinal reflex, much under the control of the cortex (p. 1041), and is liable to similar disorders of function.

FIG. 916.—The dura mater and its processes. Exposed by the removal of a part of the right half of the skull, and the brain. Semi-diagrammatic.



The *upper motor neurone* (p. 1070) is affected in hemiplegia, the *lower motor neurone* in poliomyelitis; both these systems of neurones are diseased together in the somewhat rare disorders known as amyotrophic lateral sclerosis and progressive muscular atrophy. The chief symptom here is wasting and weakness in certain groups of muscles; the palsy is flaccid, with loss of the reflexes, or spastic, with increased reflexes, according as to whether the degeneration mainly involves the lower or the upper motor neurone. The sphincters are affected only in the later stages of these diseases.

THE MEMBRANES OF THE BRAIN AND SPINAL MEDULLA

The brain and the spinal medulla are enveloped by three membranes [meninges], named from without inwards: the dura mater, the arachnoid and the pia mater.

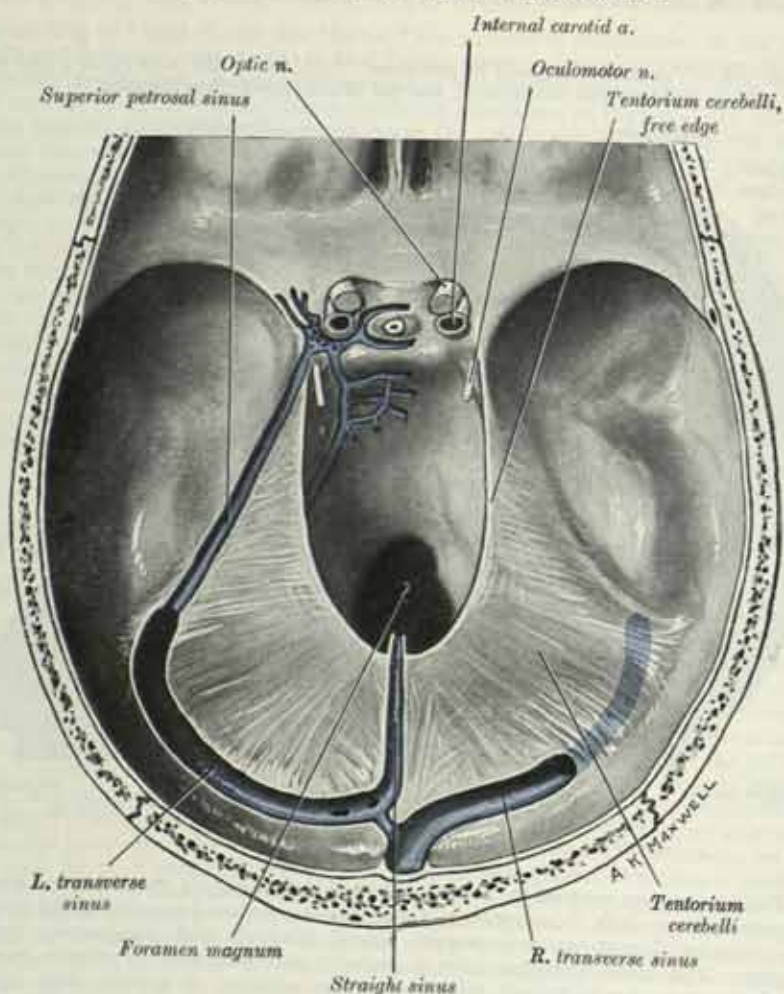
THE DURA MATER

The **dura mater** is a thick and dense inelastic membrane. The portion of it which encloses the brain (cerebral dura mater) differs in several particulars from that which surrounds the spinal medulla (spinal dura mater), and therefore it is necessary

to describe them separately; the two parts, however, form one complete membrane, and are continuous with each other at the foramen magnum.

The **cerebral dura mater** lines the interior of the skull, and serves the two-fold purpose of an internal periosteum to the bones, and a protective membrane for the brain. It is composed of two layers, an inner or meningeal and an outer or endosteal; these are closely united, except along certain lines where they are separated by the venous sinuses which drain the blood from the brain (p. 847). The dura

FIG. 917.—The tentorium cerebelli. Superior surface.



mater adheres to the inner surfaces of the cranial bones, and sends blood-vessels and fibrous processes into them, the adhesion being most marked at the sutures, at the base of the skull, and around the foramen magnum. The blood-vessels and fibrous processes are torn across when the dura mater is detached from the bones, and consequently the outer surface of the membrane presents a rough and fibrillated appearance; the inner surface is smooth and lined by a layer of mesothelium. The endosteal layer of the dura mater is continuous through the sutures and the foramina of the skull with the pericranium, and through the superior orbital fissure with the periosteal lining of the orbital cavity. It provides tubular sheaths for the cranial nerves as the latter pass through the foramina at the base of the skull. Outside the skull these sheaths fuse with the epineurium of the nerves, and the sheath of the optic nerve is continuous with the sclera of the eyeball.

The meningeal layer of the cerebral dura mater sends inwards four processes or septa which divide the cranial cavity into a series of freely communicating spaces

for the lodgment of the subdivisions of the brain. These processes are covered on their free surfaces by mesothelium, and they contain a variable quantity of white fibrous and yellow elastic tissue.

(1) The *falx cerebri* (fig. 916), so named from its sickle-like form, is a strong, arched process of dura mater which descends vertically in the longitudinal fissure between the cerebral hemispheres. It is narrow in front, where it is fixed to the crista galli of the ethmoid bone; and broad behind, where it blends in the median plane with the upper surface of the tentorium cerebelli; the narrow, anterior part is thin, and is frequently perforated by numerous apertures. The upper margin of the falx cerebri is convex, and attached to the inner surface of the skull on each side of the median plane, as far back as the internal occipital protuberance; the superior sagittal sinus (p. 847) runs along this margin. Its lower margin is free and concave, and contains the inferior sagittal sinus. The straight sinus runs along its attachment to the tentorium cerebelli.

(2) The *tentorium cerebelli* (fig. 917) is a crescentic, arched lamina of dura mater which covers the cerebellum, and supports the occipital lobes of the cerebrum. Its concave, anterior border is free, and between it and the dorsum sellæ of the sphenoid bone there is a large oval opening, named the *tentorial notch*, which is occupied by the mid-brain and the anterior part of the superior vermis of the cerebellum. Its convex outer border is attached (a) posteriorly, to the lips of the transverse sulci of the occipital bone and the postero-inferior angles of the parietal bones, where it lodges the transverse sinuses; (b) laterally, to the superior borders of the petrous parts of the temporal bones, where it encloses the superior petrosal sinuses. Near the apex of the petrous part of the temporal bone the dura mater of the posterior cranial fossa is pouched forwards and laterally to form a recess between the floor of the middle cranial fossa and its dural covering. The recess is termed the *cavum trigeminale* because it contains the roots, ganglion and the adjoining parts of the divisions of the trigeminal nerve. In its formation the lower layer of the tentorium is carried forwards and laterally, below the superior petrosal sinus and the dura mater in the floor of the middle cranial fossa, to form the roof of the recess. Lateral to the trigeminal ganglion, the roof of the recess becomes reflected on to the trigeminal impression on the apex of the petrous part of the temporal bone and so becomes continuous with the dura mater on the posterior aspect of that bone. Anteriorly the recess comes into relation with, and projects into, the cavernous sinus, up which it extends for at least one-half of its height*. The lateral wall of the recess is adherent to the deep surface of the dura mater which forms the lateral wall of the cavernous sinus (fig. 941). At the apex of the petrous part of the temporal bone the free and attached borders of the tentorium cross each other (fig. 917); the free borders are fixed to the anterior, and the attached borders to the posterior, clinoid processes of the sphenoid bone. As already described, the straight sinus runs in the line of attachment of the posterior part of the inferior border of the falx cerebri to the tentorium cerebelli.

(3) The *falx cerebelli* is a small, sickle-shaped process of dura mater which is situated below the tentorium cerebelli, and projects forwards into the posterior cerebellar notch. Its base, directed upwards, is attached to the posterior part of the inferior surface of the tentorium cerebelli, in the median plane; its posterior margin contains the occipital sinus, and is fixed to the internal occipital crest; its apex frequently divides into two small folds, which are lost on the sides of the foramen magnum.

(4) The *diaphragma sellæ* (fig. 917) is a small, circular, horizontal fold of dura mater, which forms a roof for the sella turcica and almost completely covers the hypophysis; a small opening in its centre transmits the infundibulum.

The arrangement of the dura mater in the central part of the middle cranial fossa requires further description. As the free edge of the tentorium cerebelli is traced forwards, it converges on the attached edge, and crosses it near the apex of the petrous part of the temporal bone. It is then continued forwards as a clearly visible ridge on the dura mater as far as the anterior clinoid process, to which it is attached. This ridge marks the junction of the roof and lateral wall of the cavernous sinus (fig. 941).

The attached edge of the tentorium cerebelli follows the superior border of the petrous part of the temporal bone and, after being crossed by the free edge, continues forwards to the posterior clinoid process as a somewhat rounded and indefinite ridge on the dura mater.

An angular interval exists between the anterior parts of the two edges (fig. 917) and in this interval the dura mater forms the roof of the cavernous sinus. In this situation

* R. D. Lockhart, *J. Anat.*, Lond., 62, 1927.

it is pierced in front by the oculomotor and behind by the trochlear nerves. These two nerves remain in close contact with the dura mater after piercing it and are carried forwards and downwards into the lateral wall of the cavernous sinus (fig. 941).

From the anteromedial portion of the lateral part of the middle cranial fossa the dura mater ascends, forming the lateral wall of the cavernous sinus. When it reaches the ridge produced by the forward continuation of the free edge of the tentorium cerebelli, it is carried medially, forming the roof of the cavernous sinus, and is here pierced by the internal carotid artery (fig. 941).

Medially, the roof of the cavernous sinus is continuous with the upper surface of the diaphragma sellæ. At, or just below, the opening in the diaphragma for the infundibulum of the hypophysis, the dura mater, arachnoid and pia mater blend with one another and with the capsule of the hypophysis, so that within the sella turcica it is impossible to differentiate the individual membranes or to recognise the subdural and subarachnoid spaces (fig. 941).

Structure.—The cranial dura mater consists of white fibrous tissue and elastic fibres arranged in flattened laminae, which are imperfectly separated by lacunar spaces and blood-vessels into the endosteal and meningeal layers, already referred to. The endosteal layer is the internal periosteum for the cranial bones, and contains the blood-vessels for their supply. At the margin of the foramen magnum it is continuous with the pericranium. The meningeal layer is lined on its inner surface by a layer of mesothelium.

The arteries of the cerebral dura mater are very numerous. Those in the anterior fossa of the skull are the anterior meningeal branches of the anterior and posterior ethmoidal and internal carotid arteries, and a branch from the middle meningeal artery. Those in the middle fossa are the middle and accessory meningeal branches of the maxillary artery; a branch from the ascending pharyngeal artery, which enters the skull through the foramen lacerum; branches from the internal carotid artery, and a recurrent branch from the lacrimal artery. Those in the posterior fossa are meningeal branches from the occipital artery, one entering the skull through the jugular foramen, and another through the mastoid foramen; the posterior meningeal branches of the vertebral artery: occasional meningeal branches from the ascending pharyngeal artery, entering the skull through the jugular foramen and anterior condylar canal.

The veins returning the blood from the cranial dura mater are described on p. 845.

The nerves of the cerebral dura mater are filaments from the ganglion of the trigeminal nerve, from the ophthalmic, maxillary, mandibular, and vagus nerves, and from the sympathetic.

The **spinal dura mater** (figs. 918, 922) forms a loose sheath around the spinal medulla, and represents only the inner, or meningeal, layer of the cerebral dura mater; the outer, or endosteal, layer ceases at the foramen magnum, its place being taken by the periosteum lining the vertebral canal, which is separated from the spinal dura mater by an interval, termed the *extradural space*. The spinal dura mater is attached to the circumference of the foramen magnum, and to the posterior surfaces of the bodies of the second and third cervical vertebrae; it is also connected by fibrous slips to the posterior longitudinal ligament of the vertebrae, especially near the lower end of the vertebral canal. The subdural cavity ends at the lower border of the second sacral vertebra; below this level the dura mater closely invests the filum terminale of the spinal medulla and descends to the back of the coccyx, where it blends with the periosteum. The dura mater gives tubular prolongations to the roots of the spinal nerves and to the spinal nerves themselves as they pass through the intervertebral foramina (fig. 922). These prolongations are short in the upper part of the vertebral column, but gradually become longer below, owing to the increasing obliquity of the nerve roots (p. 931).

The **extradural space** lies between the spinal dura mater and the periosteum and ligaments lining the vertebral canal; it contains a quantity of loose fat and areolar tissue and a plexus of veins. The situation of these veins relative to the spinal dura mater corresponds to that of the cranial sinuses relative to the cerebral dura. The loose fat and areolar tissue of the space, which is known to clinicians as the *epidural space*, extends laterally for a short distance through the intervertebral foramina along the spinal nerves. It has been shown* that dyes or other fluids injected into the sacral hiatus under pressure can spread upwards to the base of the skull in the extradural space, and that local anæsthetics injected in the neighbourhood of one spinal nerve immediately outside the intervertebral foramen may spread

* R. R. Macintosh and W. W. Mushin, *Anæsthesia*, July, 1947.

either upwards or downwards to affect the nerves of adjoining segments, or may spread to the opposite side. In each instance the spread occurs through the extradural space.

The **subdural space** is a potential space between the dura mater and the arachnoid mater. It contains a film of serous fluid which moistens the smooth surfaces of the opposed membranes. It does not communicate with the subarachnoid space, but is continued for a short distance on the cranial and spinal nerves, and is in free communication with the lymph-spaces of the nerves. On the optic nerve it is continued as far as the back of the eyeball.

THE ARACHNOID

The **arachnoid** is a delicate membrane enveloping the brain and spinal medulla and lying between the pia mater internally and the dura mater externally. It is separated from the dura mater by the *subdural space*, but here and there this space is traversed by isolated connective tissue trabeculae which are most numerous on the posterior surface of the spinal medulla. It is separated from the pia mater by the *subarachnoid space*, which is filled with cerebrospinal fluid.

The arachnoid surrounds the cranial and spinal nerves, and encloses them in loose sheaths as far as their points of exit from the skull and vertebral canal.

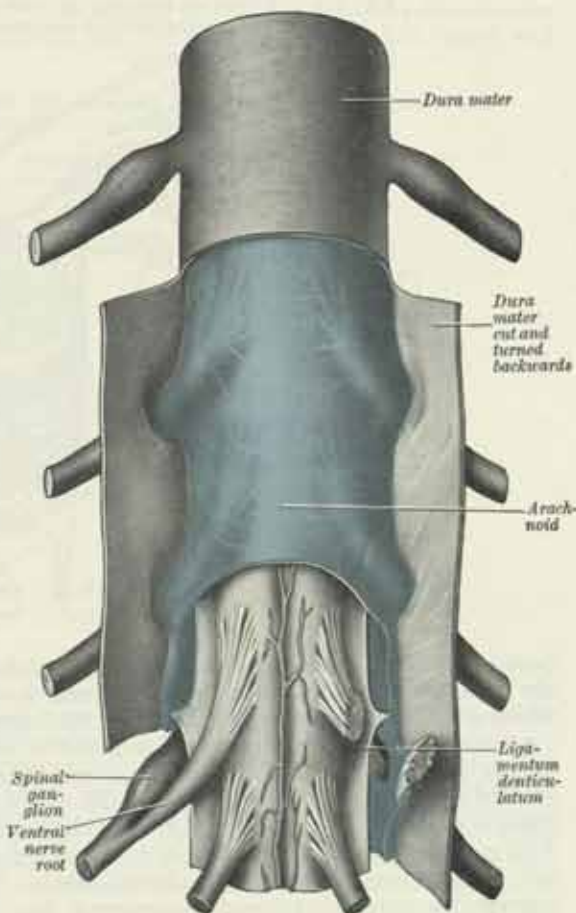
The *cerebral part of the arachnoid* invests the brain loosely, and does not dip into the sulci between the gyri, nor into the fissures, with the exception of the longitudinal fissure. On the upper surface of the brain it is thin and transparent; at the base it is thicker, and slightly opaque towards the central part, where it extends between the two temporal lobes in front of the pons, so as to leave a considerable interval between it and the pia mater. It cannot be identified in the hypophyseal fossa.

The *spinal part of the arachnoid* (figs. 918, 922) is a thin, delicate, tubular membrane loosely investing the spinal medulla. Above, it is continuous with the cerebral arachnoid; below, it widens out, invests the cauda equina, and ends at the level of the lower border of the second sacral vertebra.

Structure.—The arachnoid consists of bundles of white fibrous and elastic tissue intimately blended together. Its outer surface is covered with a layer of mesothelium. Vessels of considerable size, but few in number, and, according to Bochdalek, a rich plexus of nerves derived from the motor root of the trigeminal, the facial, and the accessory nerves, are found in the cerebral part of the arachnoid.

The **subarachnoid space** is the interval between the arachnoid and pia mater. It contains the cerebrospinal fluid and the larger blood-vessels of the brain, and is

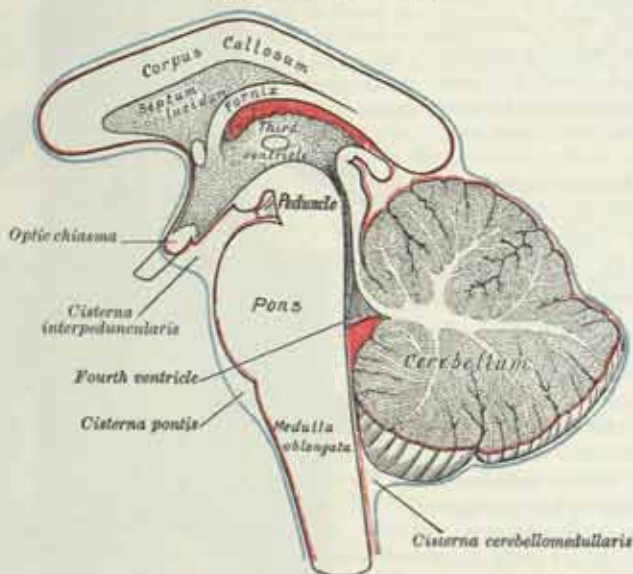
FIG. 918.—A portion of the spinal medulla, showing its membranes.



traversed by a network of delicate connective tissue trabeculae, which connect the arachnoid to the pia mater. The pia mater and the arachnoid are in close contact on the summits of the cerebral gyri; but where the arachnoid bridges the sulci, angular spaces are left, in which the subarachnoid trabecular tissue is found. At certain parts of the base of the brain, the arachnoid is separated from the pia mater by wide intervals, which communicate freely with each other and are named *subarachnoid cisternae*; in these the subarachnoid tissue is scanty and may be absent.

The subarachnoid cisternae (fig. 919).—The *cisterna cerebellomedullaris* (fig. 850) is formed by the arachnoid bridging the interval between the medulla oblongata and the under surface of the cerebellum and is triangular on sagittal section; it is continuous below with the subarachnoid space of the spinal medulla. The *cisterna pontis* (fig. 919) is an extensive space on the ventral surface of the pons. It contains the basilar artery, and is continuous below with the subarachnoid space of the spinal medulla, behind with the cerebellomedullary cisterna, and in front of the pons with the cisterna interpeduncularis. As the arachnoid extends across

FIG. 919.—A diagram showing the positions of the principal subarachnoid cisternae.



between the two temporal lobes, it is separated from the cerebral peduncles and the structures in the interpeduncular fossa by the *cisterna interpeduncularis*, which contains the *circulus arteriosus*. Anteriorly the interpeduncular cisterna is continued in front of the optic chiasma and is prolonged on the surface of the corpus callosum; here the arachnoid stretches between the cerebral hemispheres immediately below the free border of the falx cerebri, and this leaves a space in which the anterior cerebral arteries are contained. The *cisterna of the lateral fossa* contains the middle cerebral artery, and is formed in front of each temporal lobe by the arachnoid bridging the lateral sulcus. The *cisterna venæ magnæ cerebri* occupies the interval between the splenium of the corpus callosum and the superior surface of the cerebellum; it contains the great cerebral vein.

The subarachnoid space communicates with the general ventricular cavity of the brain by three openings: one, the *median aperture* (p. 985), is in the median plane in the inferior part of the roof of the fourth ventricle; the other two are at the extremities of the lateral recesses of that ventricle, behind the upper roots of the glossopharyngeal nerves (p. 984). There is no direct communication between the subdural and subarachnoid spaces. Communications exist between the tissue spaces in the nasal mucous membrane and the subarachnoid space through channels which are present along the course of the olfactory nerves.

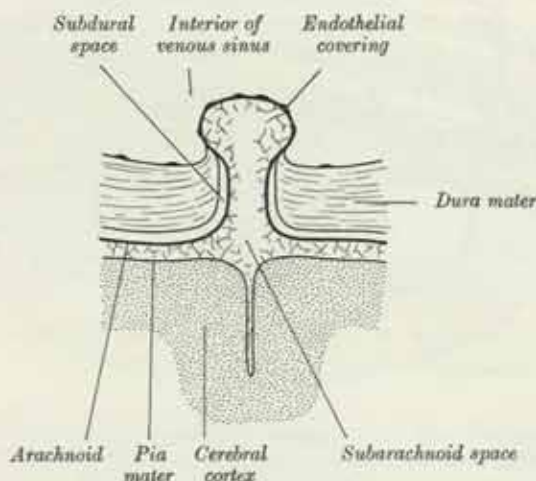
The spinal part of the subarachnoid space is a wide interval, and is largest at the lower part of the vertebral canal, where the arachnoid encloses the nerves

which form the cauda equina. Above, it is continuous with the cranial subarachnoid space; below, it ends at the level of the lower border of the second sacral vertebra. It is partially divided by two septa, termed, respectively, the *subarachnoid septum* and the *ligamentum denticulatum*. Both are described later (p. 1088).

The **arachnoid granulations** (fig. 921) are small fleshy-looking elevations, usually collected in clusters, which are present in the vicinity of the superior sagittal, transverse, and some other sinuses. When the sagittal sinus and the venous lacunæ on each side of it are opened, granulations will be found protruding into their interior (fig. 757). On close inspection they may be seen at the age of eighteen months, and at the age of three they are disseminated over a considerable area; they increase in number and size as age advances. They cause absorption of the bone, and so produce the pits or depressions on the inner aspect of the skull-cap. Arachnoid granulations are macroscopic enlargements, or distensions, of minute projections of the arachnoid mater, termed *arachnoid villi*, which are normally present in great numbers in young subjects.

Structure.—The growth and structure of the arachnoid villi and granulations have been described by Le Gros Clark.* Histologically each villus appears as a diverticulum of the subarachnoid space, penetrating into the interstices of the dura mater, and

FIG. 920.—A diagram to show the structure of a small arachnoid granulation.
(After W. E. Le Gros Clark.)



covered by a layer of flattened cells containing large oval nuclei and lightly staining protoplasm. In the subarachnoid space there is a reticulum of fine fibrous tissue, the density of which is as a rule greater at the periphery than at the centre of the granulation; in advanced age it frequently contains calcareous nodules.

At the summit of the villus the mesothelial cells proliferate and form a cap which penetrates the surrounding dura mater, and fuses with the endothelial lining of one of the intradural venous sinuses (fig. 920); in doing so it pulls out a little stalk of arachnoid containing a diverticulum of the subarachnoid space. Except at the point of fusion with the endothelial lining of the sinus, the villus is surrounded by the subdural space and the dura mater; the latter, covered on its cerebral surface by a layer of mesothelium, is invaginated into the venous sinus by the protrusion of the granulation.

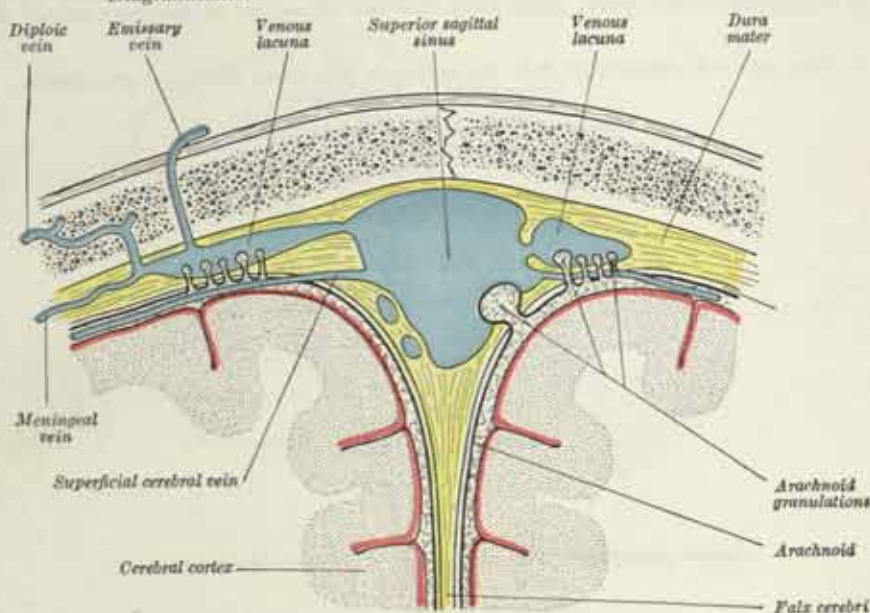
Fluid injected into the subarachnoid space passes into these granulations and villi, and it has been found experimentally that fluid passes by osmosis from the arachnoid villi into the venous sinuses of the dura mater.

The *cerebrospinal fluid* is a clear, slightly alkaline fluid, with a specific gravity of about 1007. It contains in solution inorganic salts similar to those in the blood-plasma, and also traces of protein and glucose. The cerebrospinal fluid is secreted into the ventricles of the brain by the chorioid plexuses and into the subarachnoid space by the chorioid plexuses of the lateral recesses of the fourth ventricle (p. 986). From the ventricles it passes through the median aperture and the foramina of the

* W. E. Le Gros Clark, *J. Anat.*, Lond., 55, 1920.

lateral recesses of the fourth ventricle and so gains the subarachnoid space in the cisterna cerebellomedullaris and the cisterna pontis. Within the cranium the cerebrospinal fluid flows upwards through the gap in the tentorium cerebelli and then forwards and laterally over the inferior surface of the cerebrum. Finally it ascends over the lateral aspect of each hemisphere to reach the arachnoid villi associated with the superior sagittal sinus, and so is able to pass back again into the bloodstream. It is generally held that within the vertebral canal there is no active flow, but that the process of diffusion and alterations of posture serve to maintain the character of the fluid constant throughout the whole extent of the subarachnoid space. This is not altogether convincing, and recent experimental work * suggests that the spinal cerebrospinal fluid may drain back locally into the venous system, through the vertebral venous plexuses, the intervertebral veins and the posterior intercostal and upper lumbar veins into the azygos vein. The cerebrospinal fluid supports and protects the delicate structure of the brain and spinal medulla, and it maintains a uni-

FIG. 921.—A coronal section through a part of the top of the skull to show the arrangement of the veins and the membranes of the brain, etc. Diagrammatic.



form pressure upon them. In addition, since the perforating branches of the cerebral arteries are accompanied by perivascular channels which communicate with the subarachnoid space, on the one hand, and perineuronal spaces on the other, the cerebrospinal fluid comes into intimate relation with the nerve-cells of the cortex and basal nuclei. Our knowledge of the circulation of the cerebrospinal fluid and of the arachnoid villi has, to a large extent, been built up on the work of Weed and his collaborators.†

Applied Anatomy.—Diseases of the central nervous system and its membranes are often reflected in alterations of the cells which are normally found in the cerebrospinal fluid or in alterations in the concentration of its chemical constituents. Interference with the circulation of the fluid is indicated by variations in the pressure within the meninges. The determination of these alterations and variations is often of service in diagnosis.

Specimens of the cerebrospinal fluid may be obtained by the operation of *lumbar puncture*, which is performed through the interval between the laminae or spines of the third and fourth (or fourth and fifth) lumbar vertebrae. A fine trocar and cannula is inserted at the point of intersection of the intertubercular plane with the posterior median line and is passed obliquely upwards and forwards above the upper border of the spine of the fourth lumbar vertebra. It is carried through, or parallel to, the

* F. Howarth and E. R. A. Cooper, *Lancet*, 2, 1949.

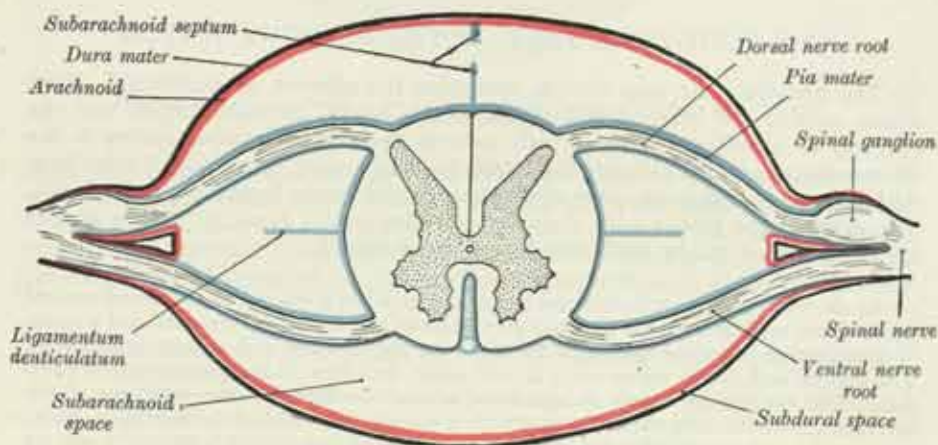
† L. H. Weed, *Contr. Embryol.*, Carneg. Instn., 9, 1920, and *J. Anat.*, Lond., 72, 1938.

supraspinous and interspinous ligaments into the vertebral canal. The dura mater and the arachnoid are punctured and the instrument is introduced into the subarachnoid space below the lower end of the spinal medulla (fig. 810). When the trocar is withdrawn, the cerebrospinal fluid escapes through the cannula at the rate of one drop per second, under normal conditions, but when the fluid is under increased pressure it escapes in an almost continuous stream. If it is suspected that the cerebrospinal fluid is under increased pressure, a manometer should be attached to the cannula, lest the sudden fall in pressure, which would otherwise occur, should lead to impaction of the medulla oblongata in the foramen magnum, causing sudden death.

THE PIA MATER

The **pia mater** closely invests the brain and spinal medulla; it is a vascular membrane, consisting of a plexus of minute blood-vessels held together by an extremely fine areolar tissue. The *cerebral pia mater* invests the entire surface of the brain, dips between the cerebral gyri and between the cerebellar laminae, and is invaginated

FIG. 922.—A transverse section through the spinal medulla and its membranes. Diagrammatic.



to form the tela chorioidea of the third ventricle, and the chorioid plexuses of the lateral and third ventricles (pp. 1018 and 1069); as it passes over the roof of the fourth ventricle, it forms the tela chorioidea and the chorioid plexuses of this ventricle (p. 985). Upon the surfaces of the hemispheres it gives off from its deep surface a multitude of sheaths around the minute vessels that run perpendicularly for some distance into the cerebral substance. On the cerebellum the membrane is more delicate; the vessels from its deep surface are shorter, and its relations to the cortex are not so intimate. Like the arachnoid, the pia mater cannot be identified in the hypophyseal fossa.

The *spinal pia mater* (figs. 918, 922) is thicker, firmer, and less vascular than the cerebral pia mater; this is due to the fact that it consists of two layers, the outer or additional one being composed of bundles of white connective tissue fibres, arranged for the most part longitudinally. Between the layers are cleft-like spaces which communicate with the subarachnoid space, and a number of blood-vessels. The spinal pia mater covers the spinal medulla, and is intimately adherent to it; in front it dips into the anterior median fissure and lines its walls, the two layers involved being connected by a loose open meshwork of fine fibrous strands (fig. 922). A longitudinal fibrous band, called the *linea splendens*, extends along the median plane anteriorly. A fibrous sheet, named the *ligamentum denticulatum*, is situated on each side (fig. 918), and a somewhat similar sheet, termed the *subarachnoid septum*, is present posteriorly (fig. 922). Below the conus medullaris the pia mater is continued as a long slender filament, named the *filum terminale* (p. 929).

The pia mater forms sheaths for the cranial and spinal nerves; these sheaths are closely connected with the nerves, and blend with their common membranous investments.

The **ligamentum denticulatum** (figs. 918, 922) is a narrow, fibrous sheet situated on each side of the spinal medulla, between the ventral and the dorsal nerve-roots. Its medial border is continuous with the pia mater at the side of the spinal medulla. Its lateral border presents a series of triangular tooth-like processes, the points of which are fixed at intervals to the dura mater. These processes are twenty-one in number, on each side. The first process crosses behind the vertebral artery at the point where that vessel pierces the dura mater, and is separated by the artery from the ventral root of the first cervical nerve; it is attached to the dura mater immediately above the margin of the foramen magnum, a short distance behind the hypoglossal nerve, and the spinal part of the accessory nerve ascends on its posterior aspect (fig. 827). The last process is between the exits of the twelfth thoracic and first lumbar nerves, and consists of a narrow oblique band running downwards and laterally from the conus medullaris (fig. 918).

The **subarachnoid septum** is an interrupted sheet of fibrous tissue, situated in the median plane. It connects the arachnoid to the pia mater opposite the posterior median sulcus (fig. 922). Incomplete and cribriform in the cervical region, it forms a more complete partition in the thoracic region.

THE PERIPHERAL PART OF THE NERVOUS SYSTEM

The peripheral nervous system comprises the afferent, or centripetal, fibres which connect the sensory end-organs to the central nervous system, and the efferent, or centrifugal, fibres which connect the central nervous system to the effector apparatus. It includes the twelve pairs of cranial nerves which arise from the brain, and the thirty-one pairs of spinal nerves which arise from the spinal medulla. The sympathetic trunks with their various ganglia and branches belong to this system, but they will be dealt with in a separate section.

In the most primitive vertebrates the spinal medulla gives rise to a series of ventral nerve-roots, arising from the anterior grey column and motor in function, and a series of dorsal nerve-roots, connected to the posterior grey column and sensory in function. The ventral and dorsal nerve-roots do not unite, and they do not correspond in position. The ventral nerve-root is segmental and is distributed to the myotome which corresponds to the neuromere from which it arises. The dorsal nerve-root is intersegmental in position and runs in the intersegmental connective tissue to reach its cutaneous distribution. In the majority of fishes and in all higher forms the corresponding ventral and dorsal nerve-roots which emerge from the spinal medulla unite with one another to constitute the individual spinal nerves. The arrangement of the spinal nerves, therefore, follows a very primitive pattern and has not undergone much modification in the process of evolution.

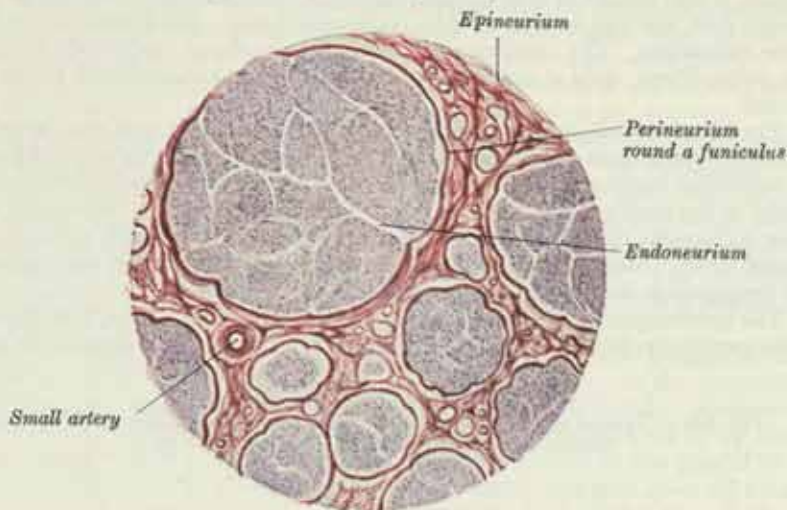
The arrangement of the cranial nerves, on the other hand, has been very profoundly modified. The development and modification of the branchial system and the suppression of segments owing to the elaborate changes which occur in the region of the head have been largely responsible for this modification. In the brain, corresponding ventral and dorsal nerves *never* fuse, although adjoining ventral or dorsal nerves may and actually do unite. Owing to the complete disappearance of certain myotomes the corresponding ventral nerves become completely suppressed. Further, the dorsal nerves, originally sensory nerves supplying chiefly the skin of the head and the mucous membrane of the mouth and pharynx acquire motor fibres which they distribute to the musculature arising in the branchial region (p. 119). With the growth and modification of the brain and the consequent elaboration of the head region, the cutaneous areas of the head are transferred from one nerve to its neighbour, so that the functions of the individual dorsal nerves become altered.

The incorporation of some of the precervical segments in the head leads to the fusion of the corresponding ventral nerves, and the hypoglossal nerve so formed becomes added to the cranial nerves.

THE STRUCTURE OF THE PERIPHERAL NERVES AND GANGLIA

The **cerebrospinal nerves** consist of numerous nerve-fibres collected into bundles, which are enclosed in membranous sheaths (fig. 923): a small bundle of fibres is called a *funiculus*. Each funiculus is surrounded by a sheath, named the

FIG. 923.—A transverse section through a number of funiculi of a human nerve. Stained with haematoxylin and eosin. (Drawn from a preparation kindly lent to the Editors by Dr. E. E. Hewer.) Low power view.



Note.—Many of the nerve-fibres are cut with varying degrees of obliquity and relatively few are cut transversely.

perineurium; this consists of a fine, smooth, transparent membrane, made up of connective tissue which has a lamellar arrangement; the sheath may be easily separated, in the form of a tube, from the fibres it encloses. The nerve-fibres are ensheathed, held together and supported within the funiculus by delicate connective tissue called the *endoneurium* (p. 41); it is continuous with septa which pass inwards

FIG. 924.—Part of a section through a human spinal ganglion, stained with haematoxylin and eosin. $\times 5250$.

The envelope which encloses the ganglion is shown at the top of the figure. The small oval or spherical nuclei in the immediate vicinity of the ganglion cells, and often overlapping them, belong to the nucleated capsules.

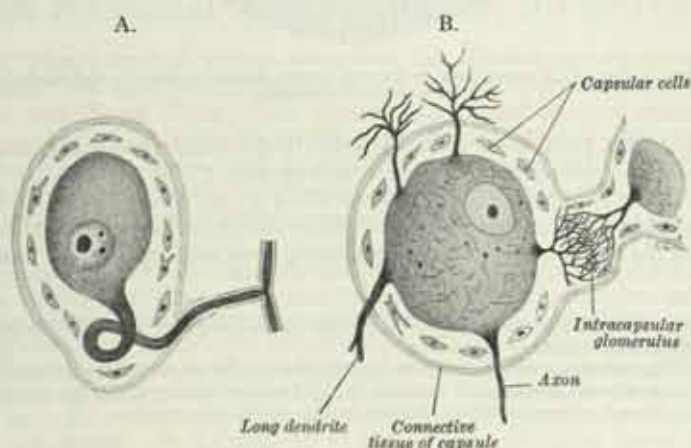


from the perineurium, and shows a ground substance in which are imbedded fine bundles of collagenous fibres running for the most part longitudinally. If the nerve is small, it may consist of only a single funiculus; but if large, it consists of several funiculi held together and invested by connective tissue; this investment is known as the *epineurium*. The cerebrospinal nerves consist almost exclusively of medullated nerve-fibres, only a very small proportion of non-medullated fibres being present.

The blood-vessels, supplying a nerve, end in a minute plexus of capillaries which pierce the perineurium, and run, for the most part, parallel with the fibres; they are connected together by short, transverse vessels, forming narrow, oblong meshes, similar to the capillary system of muscle. Fine, non-medullated, vasomotor nerve-fibres accompany these vessels, and break up into fine fibrils which form a network around them. Medullated fibres, termed *nervi nervorum*, run in the epineurium and terminate in oval or bulbous corpuscles (pp. 920, 921).

The cerebrospinal nerve-fibres pursue an uninterrupted course from the centre to the periphery, but in separating a nerve into its component funiculi, it may be

FIG. 925.—Typical nerve-cells: A. from a human spinal ganglion, and B. from a human sympathetic ganglion. (After de Castro.)



seen that bundles of fibres from one funiculus occasionally join, at a very acute angle, another funiculus proceeding in the same direction.

In their course, nerves subdivide into branches, and these frequently communicate with branches of neighbouring nerves; such communications form what is called a *nerve-plexus*. Sometimes a plexus is formed by the primary branches of the trunks of the nerves—as, for example, the cervical, brachial, lumbar, and sacral plexuses—and occasionally by the terminal funiculi, as in the plexuses formed at the periphery of the body. In the formation of a plexus, the component nerves divide, then join, and again subdivide in such a complex manner that the individual funiculi become intricately interlaced; so that each branch leaving a plexus may contain filaments from all the primary nerve-trunks entering the plexus. In the formation also of smaller plexuses at the periphery of the body there is a free interchange of funiculi and fibres. In each case, however, the individual fibres remain separate and distinct.

Through this interchange of fibres, every nerve leaving a plexus gains a more extensive connexion with the spinal medulla than if it had proceeded direct to its distribution without joining other nerves.

Origins of nerves.—The origin of a nerve is in some cases single—that is to say, the whole nerve emerges from the central nervous system by a single root; in other instances the nerve arises by two or more roots. The point where the nerve-root or roots emerge from the surface of the central nervous system is named the *superficial origin*, but the fibres of the nerve can be traced to groups of nerve-cells in the grey matter; these cell-groups constitute the *deep origin* of the nerve. The

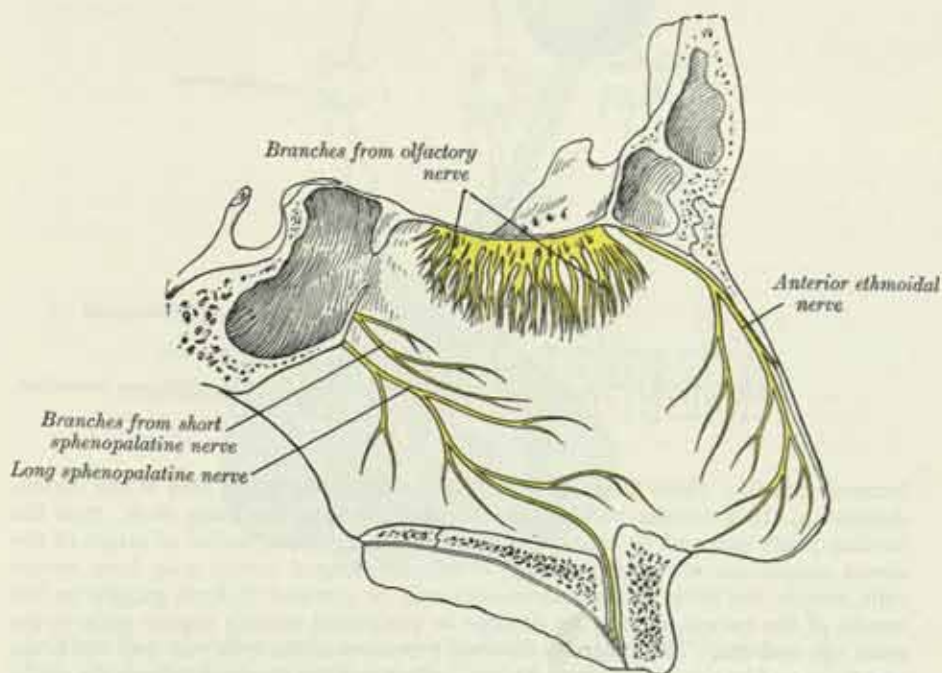
centrifugal, or efferent, nerve-fibres are the axons of nerve-cells situated in the grey matter of the central nervous system. The centripetal, or afferent, nerve-fibres spring from nerve-cells in the organs of special sense (e.g. the retina) or from nerve-cells in the ganglia. Having entered the central nervous system they branch and send their ultimate twigs to terminate in association with nerve-cells there.

Peripheral terminations of nerves.—The terminations of the sensory nerves are dealt with on pp. 920-921, and those of motor nerves on pp. 925-927.

Ganglia are aggregations of nerve-cells found on some peripheral nerves. They are present on the posterior roots of the spinal nerves; on the sensory roots of the trigeminal, facial glossopharyngeal, and vagus nerves and on the stato-acoustic (auditory) nerves. They are also found in connexion with the autonomic nerves. They vary considerably in form and size. Each ganglion is invested by a smooth, firm, membranous envelope, consisting of fibro-arcular tissue; this envelope is continuous with the perineurium of the nerves, and sends numerous processes into the interior of the ganglion.

Ganglia consist of nerve-cells and nerve-fibres. In the spinal ganglia the cells are large, uni-polar, and occur in groups round the periphery; in the sympathetic ganglia they are multipolar and are scattered more or less uniformly. Each nerve-cell has a nucleated capsule which is continuous with the neurolemma of the nerve-fibre connected with the cell. The typical larger nerve-cells in the ganglia of the spinal nerves (fig. 924) are irregularly spherical in shape, and each gives off a single fibre which runs towards the centre of the ganglion, and divides in a T-shaped manner; one limb of the cross-bar enters the spinal medulla, the other passes outwards to the periphery. Near its origin the stem of the axon is coiled on itself, forming a *glomerulus*. As it straightens out it acquires a medullary sheath, and it usually divides at its first node of Ranvier. The typical smaller cells, which are very numerous, give off fine unmyelinated fibres. These axons do not form such com-

FIG. 926.—The nerves of the septum of the nose. Right side.



plicated glomeruli and they may be practically straight. The presence of plexuses of finely medullated or unmyelinated fibres around the cell-bodies has been described by Dogiel, who regards them as being sympathetic in origin. The same authority has described several additional varieties of cells in the spinal ganglia. In one type, the peripheral division of the axons breaks up within the ganglion into sensory nerve-

endings; in another, the cell is multipolar and, while the medullated axon passes centrally into the spinal medulla, the dendrites, which are peculiar in that they may be partly medullated, break up into sensory endings within the ganglion.

Structurally the peripheral division of the axon of an unipolar ganglion cell resembles an axon in every respect, but it functions as a greatly elongated dendrite.

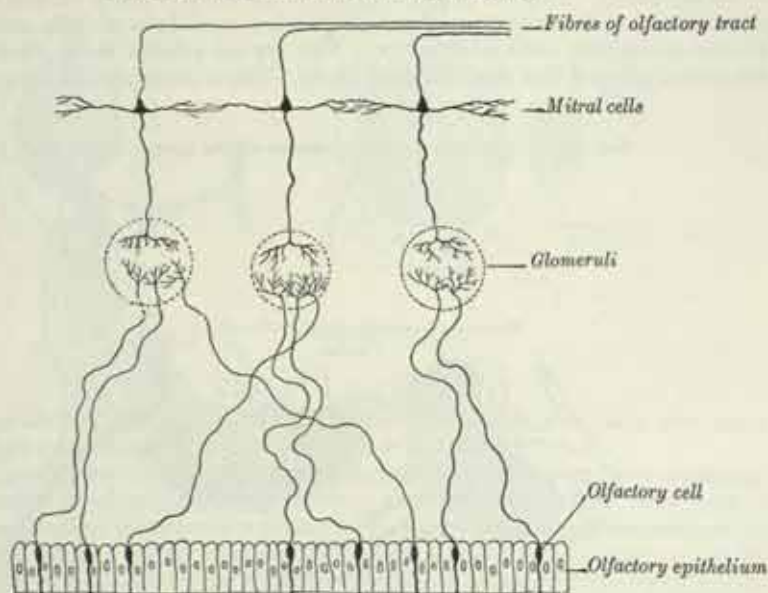
THE CRANIAL NERVES

There are twelve pairs of cranial nerves, which are named from before backwards as follows:

1st. Olfactory.	5th. Trigeminal.	9th. Glossopharyngeal.
2nd. Optic.	6th. Abducent.	10th. Vagus.
3rd. Oculomotor.	7th. Facial.	11th. Accessory.
4th. Trochlear.	8th. Stato-acoustic (Auditory).	12th. Hypoglossal.

These nerves are attached to the brain, and are transmitted through openings in the base of the cranium. The **motor**, or efferent, cranial nerves arise within the brain from groups of nerve-cells which constitute their *nuclei of origin*. They are brought into relationship with the cerebral cortex by the geniculate fibres of the

FIG. 927.—A plan of the olfactory neurones.



internal capsule; these fibres arise from the cells of the motor area of the cortex, descend in the genicular part of the internal capsule to the brain stem, cross the median plane and end by arborising round the cells of the nuclei of origin of the motor cranial nerves. The **sensory**, or afferent, cranial nerves arise from nerve-cells outside the brain; these nerve-cells may be grouped to form ganglia on the trunks of the nerves, or may be situated in peripheral sensory organs such as the nose, eye and ear. The centrally directed processes of the cells run into the brain and there end by arborising around nerve-cells which are grouped to form the *nuclei of termination* of the ordinary sensory nerves. Fibres arise from the cells of these nuclei and, after crossing to the opposite side, join the lemnisci, and thus connect the nuclei indirectly with the cerebral cortex.

The fibres of most of the cranial nerves begin to acquire their myelin sheaths about the fourteenth week of intrauterine life. The process is delayed until the twenty-second week in the cases of the sensory part of the trigeminal nerve and the

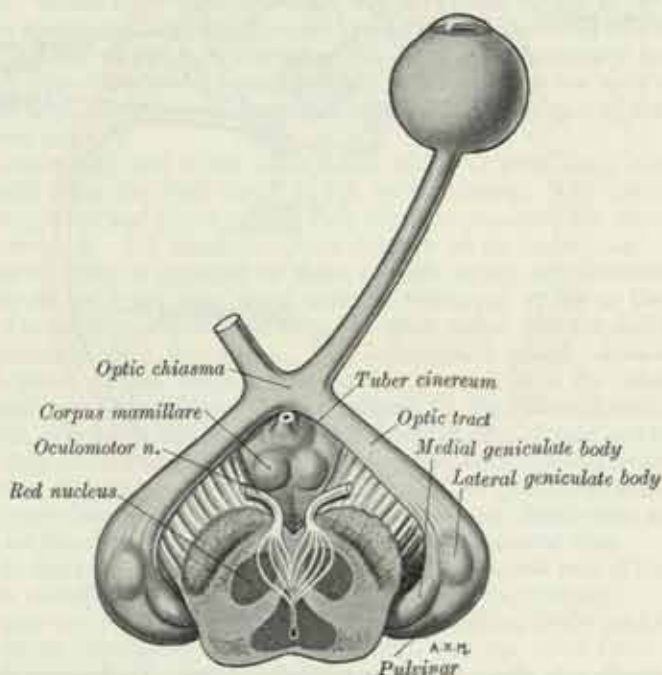
cochlear division of the stato-acoustic nerve. In the case of the optic nerve myelination does not commence until shortly before birth, and it is not completed until the second week after birth.*

THE OLFACTORY NERVES (fig. 926)

The **olfactory nerves**, or nerves of smell, are distributed to the mucous membrane of the olfactory region of the nasal cavity; this region comprises the superior nasal concha, and the opposed part of the nasal septum. The nerve-fibres originate from the central, or deep, processes of the olfactory cells (fig. 927) of the nasal mucous membrane, and are collected into bundles which cross one another in various directions, and thus give rise to the appearance of a plexiform network in the mucous membrane. They are then collected into about twenty branches, which pierce the cribriform plate of the ethmoid bone in lateral and medial groups, and end in the glomeruli of the olfactory bulb (fig. 927). Each branch receives tubular sheaths from the dura mater and pia-arachnoid, the former being continued into the periosteum of the nose, the latter into the neurolemma of the nerve. The subarachnoid space, therefore, communicates with the perineural spaces in the olfactory nerves and in this way a channel exists for the spread of nasal infection to the meninges.†

The olfactory nerves are non-medullated, and consist of axis-cylinders surrounded by nucleated sheaths, in which, however, there are fewer nuclei than in the sheaths of ordinary non-medullated nerve-fibres.

FIG. 928.—The left eyeball and optic nerve, and the optic chiasma and tracts, viewed from below.



The olfactory nerves are unique in that their cells of origin develop in the ectoderm and retain this position throughout life in all forms.

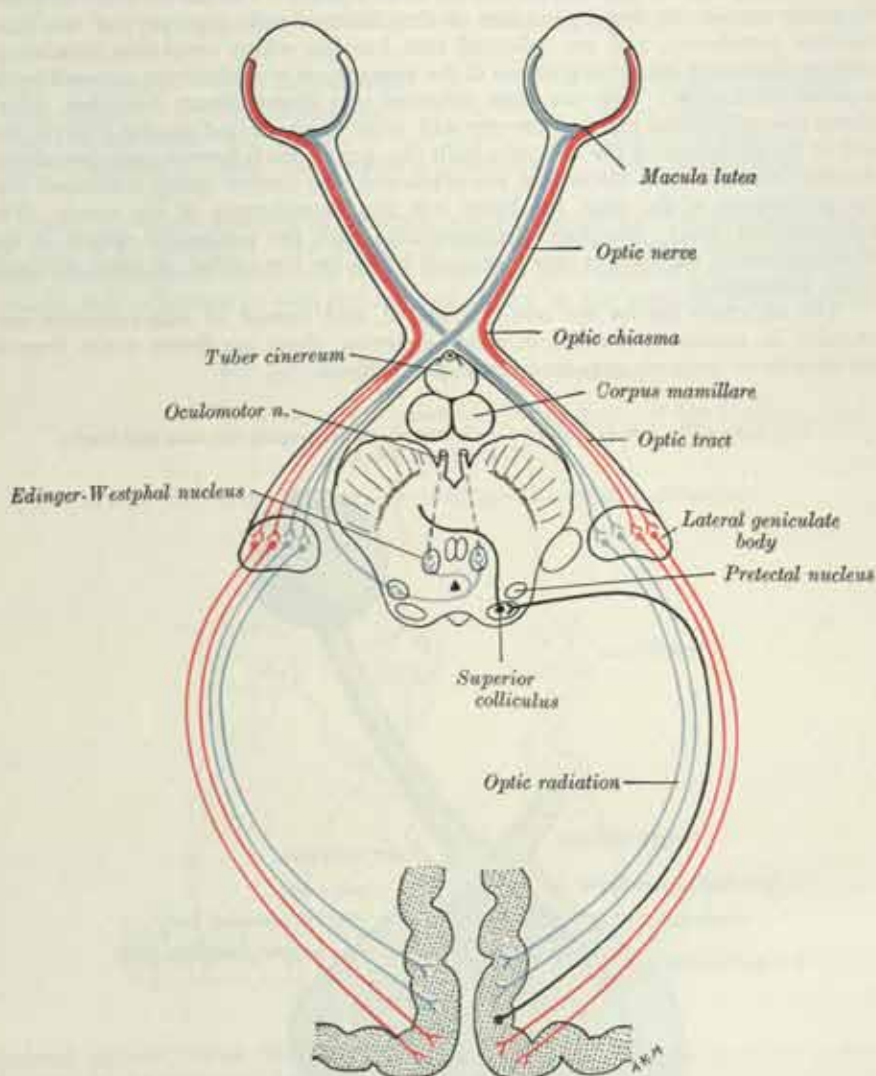
Closely associated with the olfactory nerves is a pair of small nerves named the *nervi terminales*.

* M. F. Lucas Keene and E. E. Hewer, *J. Anat.*, 66, 1931.

† W. E. Le Gros Clark. Reports on Public Health and Medical Subjects, No. 54, Ministry of Health. H.M. Stationery Office, 1929.

These nerves were first seen in the lower vertebrates, but their presence has been demonstrated in the human embryo and adult. They consist chiefly of non-medullated nerve-fibres, and on them there are small groups of bipolar and multipolar nerve-cells. Each nerve runs along the medial side of the corresponding olfactory tract, and its branches traverse the cribriform plate of the ethmoid bone, and are distributed to the nasal mucous membrane. Centrally the nerve is connected to the brain close to the anterior perforated substance; in some animals its fibres have been traced to the

FIG. 929.—A scheme showing the connexions of the optic nerves and optic tracts.



lamina terminalis: in others to the hypothalamic region. Its function is unknown; some are inclined to view it as a forward extension of the cephalic part of the sympathetic nervous system which is distributed to the blood-vessels and glands of the nasal cavity.

The central connexions of the olfactory bulb are described on pp. 1031-1035.

Applied Anatomy.—In severe injuries to the head involving the anterior cranial fossa, the olfactory bulb may become separated from the olfactory nerves, or the nerves may be torn, thus producing loss of smell (*anosmia*).

Anosmia sometimes occurs after acute infections of the nose.

THE OPTIC NERVE (fig. 929)

The **optic nerve**, or nerve of sight, is distributed to the eyeball. Nearly all its fibres are afferent and originate in the nerve-cells of the ganglionic layer of the retina (p. 1245), but a few are efferent, their source of origin being uncertain. Developmentally, the optic nerves and the retinae are parts of the brain (p. 135), and their fibres are devoid of neurolemma sheaths.

The fibres of the optic nerve form the innermost layer (*stratum opticum*) of the retina and are the axons of the cells in its ganglionic layer; they converge on the optic disc, and there pierce the outer layers of the retina, the choroid coat, and the lamina cribrosa of the sclera at the posterior part of the eyeball, about 3 or 4 mm. to the nasal side of its centre. As the nerve-fibres traverse the lamina cribrosa they receive their medullary sheaths, and run in bundles which are collected to form the optic nerve.

The optic nerve, about 4 cm. long, is directed backwards and medially through the posterior part of the orbital cavity. It then runs through the optic canal into the cranial cavity and joins the optic chiasma.

The intra-orbital part of the nerve is about 25 mm. long and has a slightly sinuous course, the length of the nerve being about 6 mm. more than the distance between the optic canal and the eyeball. Posteriorly it is closely surrounded by the recti muscles, but anteriorly is separated from them by a quantity of fat, in which run the ciliary vessels and nerves. The ciliary ganglion lies between the nerve and the rectus lateralis muscle. The inferomedial surface of the nerve is pierced, at a distance of about 12 mm. behind the eyeball, by the central artery and vein of the retina, which are then directed forwards in the centre of the nerve to the optic disc. In the optic canal the nerve lies above and medial to the ophthalmic artery, and is separated medially from the sphenoidal and posterior ethmoidal sinuses by a thin lamina of bone; in front of the canal the nasociliary nerve and the ophthalmic artery run forwards and medially, crossing above the optic nerve, whilst the branch to the medial rectus muscle from the inferior division of the oculomotor nerve passes below it.

The intracranial part of the optic nerve, about 10 mm. long, runs backwards and medially from the optic canal to the optic chiasma. The posterior parts of the olfactory tract and gyrus rectus, and, near the chiasma, the anterior cerebral artery lie above it. The internal carotid artery is on its lateral side.

The optic nerve is enclosed in three sheaths, which are continuous with the membranes of the brain (fig. 1021), and are prolonged as far as the back of the eyeball. The *outer sheath*, derived from the dura mater, is thick and fibrous, and blends anteriorly with the sclera. The *intermediate sheath*, derived from the arachnoid mater, is thin and delicate. It is separated from the outer sheath by the subdural space, and from the inner sheath by the subarachnoid space. The *inner sheath*, derived from the pia mater, is vascular and closely invests the nerve. From its deep surface septa pass into the nerve and subdivide and reunite to enclose what appear, in transverse sections of the nerve, as polygonal areas, which are occupied by the bundles of nerve-fibres. From the inner sheath also, an investment is carried on the central vessels of the retina as far as the optic disc.

Close to the eyeball the macular fibres occupy the lateral part of the nerve, but, as they are traced backwards, they gradually come to lie centrally.

The optic nerve consists of rather more than a million finely medullated fibres. Of these about one-half are 7-10 μ in diameter, and the other about 2-3 μ . The larger fibres have an average conduction rate of 60 mps. and the smaller about 25 mps. The former are destined for the lateral geniculate body where they are relayed to the striate cortex, while the latter pass to the superior colliculi (*corpora quadrigemina*) and are concerned with optical reflexes (p. 1256).

The **optic chiasma** (p. 1015), and the **optic tract** (p. 1016), have already been described.

Applied Anatomy.—The optic nerve is peculiarly liable to become the seat of neuritis or undergo atrophy in affections of the central nervous system, and as a rule the pathological relationship between the two affections is exceedingly difficult to trace. There are, however, certain points in connexion with the anatomy of this nerve

which tend to throw light upon the frequent association of its affections with intracranial disease. (1) From its mode of development, and from its structure, the optic nerve must be regarded as a prolongation of the brain-substance, rather than as an ordinary cranial nerve. (2) It receives sheaths from the three cerebral membranes, and these sheaths are separated from each other by spaces which communicate with the subdural and subarachnoid spaces respectively. The innermost sheath sends a process around the arteria centralis retinae into the interior of the nerve, and enters intimately into its structure. Thus inflammatory affections of the meninges or of the brain may readily extend along these spaces, or along the interstitial connective tissue in the nerve.

The optic neuritis or papilloedema ('choked disc') that is often seen in cases of intracranial new growth with increased intracranial tension is probably caused by increased pressure in the sheath of the optic nerve, due to excess of fluid in the general subarachnoid space with which this sheath is in direct communication. If, as is the case, for example, in the internal hydrocephalus seen as a complication of cerebrospinal fever, there is no increase in the amount of fluid in the subarachnoid space, then there will be no optic neuritis although the intracranial tension may rise until it brings about the patient's death.

THE OCULOMOTOR NERVE (figs. 928 to 933)

The **oculomotor nerve** supplies all the ocular muscles, except the obliquus superior and rectus lateralis; it also supplies, through its connexion with the ciliary ganglion, the sphincter pupillae and the ciliaris muscles.

The fibres of the oculomotor nerve arise from a **nucleus** which lies in the grey matter of the upper part of the floor of the aqueduct of the mid-brain and extends in front of the aqueduct for a short distance into the floor of the third ventricle, occupying the position of the somatic efferent column (p. 132). From this nucleus the fibres pass forwards through the tegmentum, the red nucleus and the medial part of the substantia nigra, forming a series of curves with a lateral convexity, and emerge from the sulcus on the medial side of the cerebral peduncle (fig. 928).

The nucleus of the oculomotor nerve does not consist of a continuous column of cells, but is broken up into a number of smaller nuclei: (1) the dorsilateral nucleus; (2) the ventrimedial nucleus; (3) the central nucleus; (4) the Edinger-Westphal nucleus; (5) the caudal central nucleus. The dorsilateral nucleus extends further in a headward direction than the ventrimedial nucleus, but does not extend so far caudally. The central nucleus is continuous across the median plane with the corresponding nucleus of the opposite side. These three nuclei all contain large multipolar nerve-cells, and it is believed that they supply all the striped muscle innervated by the oculomotor nerve. The evidence at present available is not conclusive, but it suggests that the dorsilateral nucleus is concerned with upward movements (superior rectus and inferior oblique muscles), the ventrimedial nucleus, which is in direct line with the nucleus of the trochlear nerve, with downward movements (inferior rectus) and the central nucleus with movements of convergence (medial rectus). The Edinger-Westphal nucleus is placed more dorsally in the central grey matter of the mid-brain and extends further in a headward direction than the other nuclei. It is generally regarded as the nucleus of origin of the fibres which innervate the sphincter pupillae and ciliary muscles. From both the right and the left nucleus these fibres pass to each oculomotor nerve.* The caudal central nucleus, which like the Edinger-Westphal nucleus contains small, stellate nerve-cells, lies in line with it and is probably similar in function.†

Recent evidence throws further doubt on the rôle of the central nucleus as a mediator of movements of convergence.

It has been suggested‡ that proprioceptive fibres from the orbital muscles travel in the oculomotor nerve to terminate in groups of nerve cells which are intimately related to the motor nuclei.

Connexions.—The oculomotor nucleus receives fibres from: (1) the pyramidal tract of the opposite side; (2) the medial longitudinal bundle, by which it is connected to the nuclei of fourth, sixth and eighth cranial nerves (p. 994); and (3) the tectobulbar tract, by which it is connected to the visual cortex through the medium of the superior colliculus.

* R. L. Crouch, *J. Comp. Neur.*, **64**, 1936.

† W. E. Le Gros Clark, *J. Anat.*, **60**, 1926.

‡ K. B. Corbin and F. Harrison, *J. Comp. Neurol.*, **73**, 1940, and **77**, 1942.

Course.—On emerging from the brain, the nerve is invested with a sheath of pia mater, and lies in the subarachnoid space. It passes between the superior cerebellar and posterior cerebral arteries (fig. 867), and runs forward in the interpeduncular cisterna on the lateral side of the posterior communicating artery. It then perforates the arachnoid mater and lies in the triangular interval between the free and attached borders of the tentorium cerebelli. Piercing the inner layer of the dura mater on the lateral side of the posterior clinoid process the nerve traverses the lateral wall of the cavernous sinus, where it lies above the trochlear nerve. In this situation it receives one or two filaments from the internal carotid plexus of the sympathetic, and communicates with the ophthalmic division of the trigeminal.* It then divides into a superior and an inferior ramus, which enter the orbit through the superior orbital fissure, within the annulus tendineus which gives origin to the recti muscles; here the nasociliary nerve is placed between the two rami.

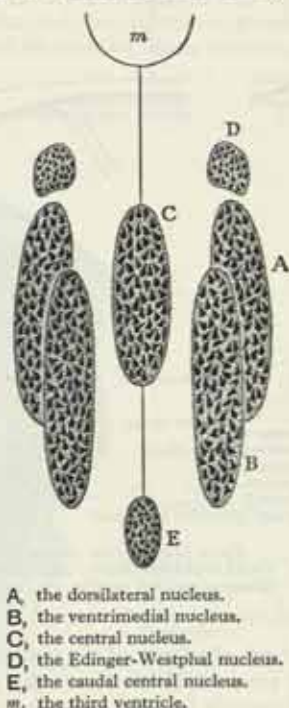
The *superior ramus*, the smaller, ascends on the lateral side of the optic nerve, and supplies the rectus superior and levator palpebrae superioris. The *inferior ramus* divides into three branches (fig. 931). One passes below the optic nerve to the rectus medialis; another goes to the rectus inferior; the third and longest runs forwards between the rectus inferior and rectus lateralis, to the obliquus inferior. From the nerve to the obliquus inferior a short thick branch is given to the lower part of the ciliary ganglion, and forms its *motor* or *parasympathetic root*. The branches enter the muscles on their ocular surfaces, with the exception of that to the obliquus inferior, which enters the posterior border of the muscle.

The **ciliary ganglion** (figs. 931, 932 and 934) is a small, flattened ganglion of a reddish-grey colour and about the size of a pin's head; it is situated near the apex of the orbit in some loose fat between the optic nerve and the rectus lateralis muscle, lying usually on the lateral side of the ophthalmic artery. It is a peripheral ganglion of the parasympathetic system and its constituent cells are multipolar.

Its *connexions* or *roots* (fig. 932) are three in number and enter or leave it posteriorly. The *motor* or *parasympathetic root* is derived from the nerve to the inferior oblique muscle and consists of preganglionic fibres which arise from the cells of the Edinger-Westphal nucleus (fig. 929). These fibres are relayed in the ganglion and the postganglionic fibres travel in the short ciliary nerves to supply the sphincter pupillae and ciliaris muscles. The *sympathetic root* is a branch from the internal carotid plexus. It may pass direct to the ganglion or it may join the sensory root and reach the ganglion indirectly. It consists of postganglionic fibres which take origin in the superior cervical ganglion and traverse the ciliary ganglion, without being interrupted, to emerge in the short ciliary nerves. They are distributed to the blood-vessels of the eyeball and occasionally they may include the fibres which supply the dilatator pupillae muscle when these fibres do not follow their usual course in the ophthalmic, nasociliary and long ciliary nerves (p. 1103). The *sensory root* is formed by a *ramus communicans* to the nasociliary nerve. It contains sensory fibres from the eyeball, which reach the ganglion in the short ciliary nerves and pass through it without being interrupted.

* Doubt has been thrown on the character of the communications between the third, fourth and sixth cranial nerves with the internal carotid plexus and the ophthalmic nerve in the cavernous sinus. See S. Sunderland and E. S. R. Hughes, *Brain*, 69, 1946.

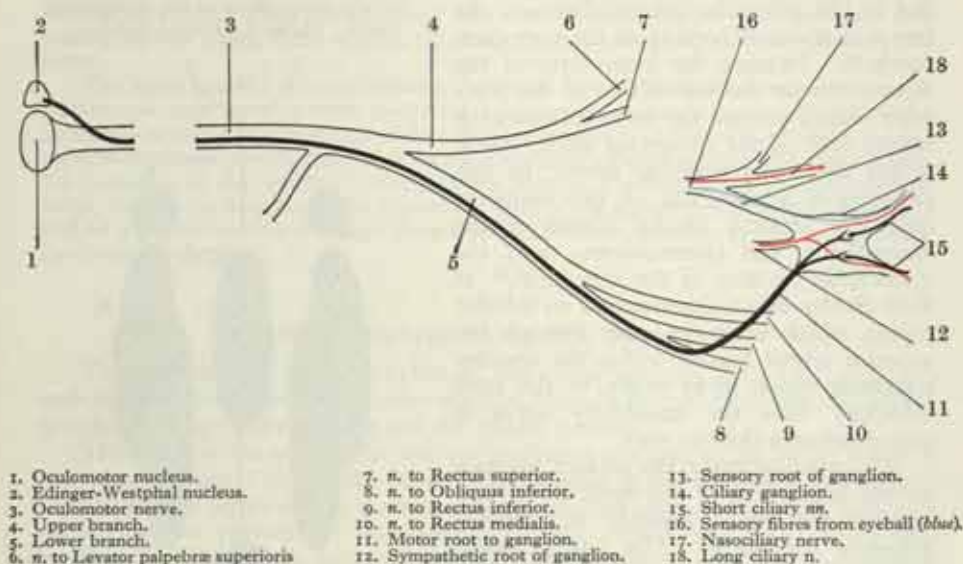
FIG. 930.—A scheme of the various groups of cells which together constitute the nucleus of the oculomotor nerve. (After Le Gros Clark.)



It leaves the ganglion posteriorly and runs backwards to join the nasociliary nerve near the point where that nerve enters the orbit.

The *branches* of the ganglion are delicate filaments, eight to ten in number, which

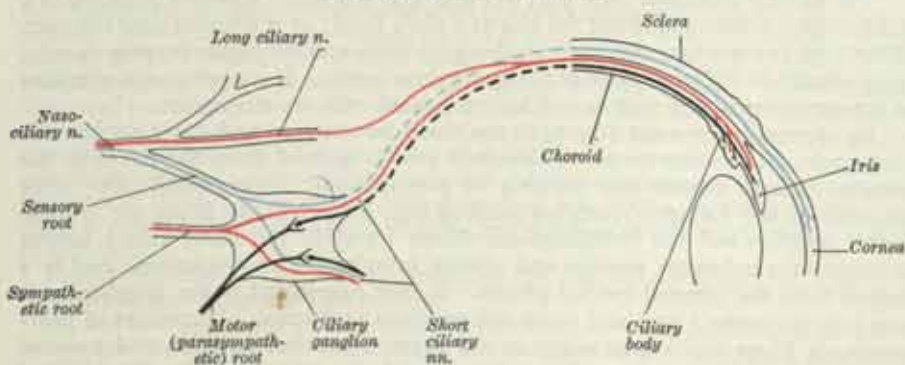
FIG. 931.—A plan of the oculomotor nerve.



Red = Sympathetic fibres: Heavy black = Parasympathetic fibres: Blue = sensory (cerebro-spinal) fibres. Alternative pathways are shown for the sympathetic fibres to the dilatator pupillae muscle.

arise from the front of the ganglion in two bundles, of which the lower is the larger. They are termed the *short ciliary nerves*. In company with the ciliary arteries they run forwards in a wavy course, one set above the optic nerve, the other below, and

FIG. 932.—A diagram showing the ciliary ganglion, with its roots and branches of distribution.



Red=sympathetic fibres. Heavy black=parasympathetic fibres. Blue=sensory (cerebro-spinal) fibres.

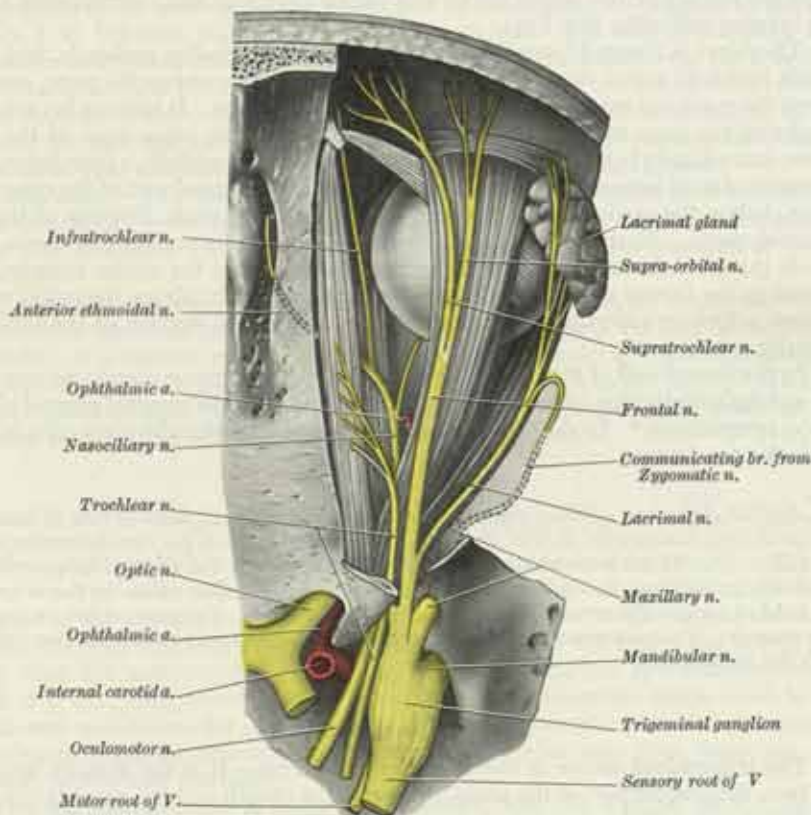
Alternative pathways are given for the sympathetic fibres to the dilatator pupillae muscle. A schematic parasagittal section is shown of the upper lateral quadrant of the eyeball, but the retina has not been included.

are related to the long ciliary nerves. They subdivide into about fifteen or twenty branches, which pierce the sclera around the entrance of the optic nerve and pass forwards in delicate grooves on the inner surface of the sclera. They contain both motor and sensory fibres; the former are distributed to the sphincter pupillae and

ciliaris muscles and to the blood-vessels of the eyeball ; the latter supply the cornea, iris and choroid.

Applied Anatomy.—Paralysis of the oculomotor nerve leads, when complete, to (1) ptosis, or drooping of the upper eyelid, on account of paralysis of the levator palpebræ superioris ; (2) lateral strabismus, on account of the unopposed action of the rectus lateralis and obliquus superior, which are not supplied by the oculomotor nerve and are therefore not paralysed ; (3) dilatation of the pupil, because the sphincter pupillæ is paralysed ; (4) loss of power of accommodation and of contraction on exposure to light, as the sphincter pupillæ and the ciliaris are paralysed ; (5) slight prominence of the eyeball, owing to most of its muscles being relaxed ; and

FIG. 933.—The nerves of the right orbit, viewed from above.



(6) diplopia, or double vision, the false image being higher than the true. Occasionally paralysis may affect only a part of the nerve—for example, there may be a dilated and fixed pupil, with ptosis, but no other signs. Irritation of the nerve causes spasm of one or other of the muscles supplied by it ; thus, there may be medial strabismus from spasm of the rectus medialis ; accommodation for near objects only, from spasm of the ciliaris ; or a contracted pupil owing to irritation of the sphincter pupillæ.

The oculomotor nerve is particularly liable to become involved in a syphilitic periarteritis, as it passes between the posterior cerebral and superior cerebellar arteries at the base of the brain.

THE TROCHLEAR NERVE (figs. 933, 943)

The **trochlear nerve**, the most slender of the cranial nerves, supplies the superior oblique muscle of the eyeball.

It arises from a **nucleus** situated in the floor of the cerebral aqueduct, opposite the upper part of the inferior colliculus. This nucleus lies in line with the ventri-

medial part of the oculomotor nucleus, and occupies the position of the somatic efferent column. It bears an intimate relationship to the medial longitudinal bundle, which lies on its ventral aspect.

Connexions.—The nucleus of the trochlear nerve receives fibres from: (1) the pyramidal tract of the opposite side; (2) the medial longitudinal bundle, by which it is connected with the nuclei of the eighth cranial nerve (p. 994); and (3) from the tectobulbar tract, through which it receives impulses from the visual cortex through the medium of the superior colliculus (p. 994).

Course.—After leaving the nucleus the fibres of the trochlear nerve pursue a very unusual course (p. 991). They first run downwards and laterally through the tegmentum and then turn backwards round the central grey matter into the upper part of the superior medullary velum. Here they decussate with the corresponding fibres of the opposite side, and, having crossed the median plane, emerge from the surface of the velum at the side of the frenulum veli, immediately below the inferior colliculus (fig. 859).

The nerve is directed laterally across the superior cerebellar peduncle, and then winds forwards round the cerebral peduncle immediately above the pons, and between the posterior cerebral and superior cerebellar arteries. It appears between the border of the pons and the temporal lobe, and pierces the inner layer of the dura mater immediately below the free border of the tentorium cerebelli, a little behind the posterior clinoid process. It then passes forwards in the lateral wall of the cavernous sinus, below the oculomotor nerve and above the ophthalmic division of the trigeminal nerve. Near the front of the sinus it crosses the oculomotor nerve, and enters the orbit through the superior orbital fissure, above the ocular muscles, and medial to the frontal nerve. In the orbit it passes medially, above the origin of the levator palpebræ superioris, and finally enters the orbital surface of the obliquus superior.

In the lateral wall of the cavernous sinus the trochlear nerve communicates with the ophthalmic division of the trigeminal nerve, and with the internal carotid plexus of the sympathetic.* In the superior orbital fissure it occasionally gives off a branch to the lacrimal nerve.

Applied Anatomy.—When the trochlear nerve is paralysed there is loss of function in the obliquus superior, so that the patient is unable to turn his eye downwards and laterally. Should the patient attempt to do this, the eye of the affected side is rotated medially, producing diplopia or double vision. Single vision exists in the whole of the field so long as the eyes look above the horizontal plane, diplopia occurs on looking downwards. To counteract this the patient holds his head forwards, and also inclines it to the sound side.

THE TRIGEMINAL NERVE

The **trigeminal nerve** is the largest cranial nerve. It is the sensory nerve of the face, the greater part of the scalp, the teeth, the mouth and the nasal cavity, and the motor nerve of the muscles of mastication. It divides into three branches, viz. the ophthalmic, the maxillary, and the mandibular.

It is attached to the anterior, or ventral, surface of the pons, near its upper border, by a large sensory, and a small motor, root—the latter being placed medial and anterior to the former.

The fibres of the *sensory root* arise from the cells of the *trigeminal ganglion*. This ganglion (figs. 933, 935) occupies a recess (*cavum trigeminale*) in the dura mater covering the trigeminal impression near the apex of the petrous part of the temporal bone (p. 1081). It lies at a depth of 4.5-5 cm. from the lateral aspect of the head, a little in front of the pre-auricular point. The ganglion is crescentic in shape, with its convexity directed forwards and laterally; its surface is obscured by a number of interlacing nerve-fibres. Medially it is in relation with the internal carotid artery and the posterior part of the cavernous sinus; inferiorly, with the motor root of the nerve, the greater (superficial) petrosal nerve, the apex of the petrous part of the temporal bone, and the foramen lacerum. It receives filaments from the internal carotid plexus of the sympathetic, and gives twigs to the tentorium cerebelli.

* See footnote p. 1097.

The axons of the cells of the trigeminal ganglion divide into peripheral and central branches. The former are grouped to form the *ophthalmic* and *maxillary* nerves, and the sensory part of the *mandibular* nerve. The central branches constitute the fibres of the sensory root of the nerve, which leaves the concave margin of the ganglion, runs backwards and medially below the superior petrosal sinus and the tentorium cerebelli, and enters the pons. The manner in which these fibres behave on entering the pons has been described on p. 968.

In addition to the **Superior sensory nucleus** and the **Nucleus of the spinal tract of the trigeminal nerve**, which have already been described in detail (p. 966), a third sensory nucleus, termed the **Mesencephalic nucleus**, is associated with the sensory root of the nerve. This nucleus consists of a strand of cells occupying nearly the whole length of the lateral portion of the central grey matter of the mid-brain. It was originally regarded as an additional motor nucleus, but, on the grounds of its histological characters and its developmental position in the alar lamina, J. B. Johnston claimed it as a sensory nucleus. The view of Kappers, that it receives proprioceptive fibres from the muscles of mastication (p. 991), is now widely accepted, and there is some ground for believing that it bears a similar relation to the muscles of the orbit.* It apparently constitutes a nucleus of origin, as the fibres of the mesencephalic root of the trigeminal nerve, which runs upwards on its lateral side, pass through the trigeminal ganglion without interruption.

Connexions.—The new fibres which arise in these sensory nuclei cross the median plane and ascend to the lateral nucleus of the thalamus in the trigeminal lemniscus. From the thalamus they are relayed to the cortex of the postcentral gyrus (p. 1034).

The **motor nucleus** of the trigeminal nerve (p. 967) lies in the upper part of the pons, close to its dorsal surface, and along the lateral margin of the floor of the fourth ventricle. It is further from the median plane than the nuclei of the oculomotor and trochlear nerves, and it occupies the position of the branchial (special visceral) efferent column (fig. 836). It receives fibres from the pyramidal tract of the opposite side, and its outgoing fibres form the motor root.

THE OPHTHALMIC NERVE (figs. 933, 934)

The **ophthalmic nerve**, the first division of the trigeminal nerve, is a sensory nerve. It supplies branches to the eyeball, the lacrimal gland and the conjunctiva, to a part of the mucous membrane of the nasal cavity, and to the skin of the nose, eyelids, forehead and scalp. It is the smallest division of the trigeminal nerve, and arises from the anteromedial part of the trigeminal ganglion as a flattened band, about 2.5 cm. long, which passes forwards in the cavernous sinus close to its lateral wall and below the oculomotor and trochlear nerves; just before entering the orbit through the superior orbital fissure, it divides into three branches, viz. *lacrimal*, *frontal* and *nasociliary*.

The ophthalmic nerve is joined by filaments from the internal carotid plexus of the sympathetic, and communicates with the oculomotor, trochlear and abducent nerves; † it supplies a recurrent branch (n. tentorii), which crosses and adheres to the trochlear nerve, and is distributed to the tentorium cerebelli.

The **lacrimal nerve** (fig. 933) is the smallest branch of the ophthalmic nerve. It sometimes receives a filament from the trochlear nerve, but possibly this filament consists of fibres which have previously passed from the ophthalmic to the trochlear nerve. The lacrimal nerve enters the orbit through the lateral part of the superior orbital fissure, runs along the upper border of the rectus lateralis with the lacrimal artery, and receives a twig from the zygomatic branch of the maxillary nerve, conveying secretomotor fibres for the lacrimal gland. It enters the lacrimal gland and gives off several filaments to the gland and the conjunctiva. Finally it pierces the orbital septum, and ends in the skin of the upper eyelid, joining with filaments of the facial nerve.

The lacrimal nerve is occasionally absent, and its place is then taken by the zygomatic nerve.

* H. H. Woollard, *J. Anat.*, **65**, 1931. See also K. B. Corbin and F. Harrison, *J. Comp. Neurol.*, **73**, 1940, and **77**, 1942.

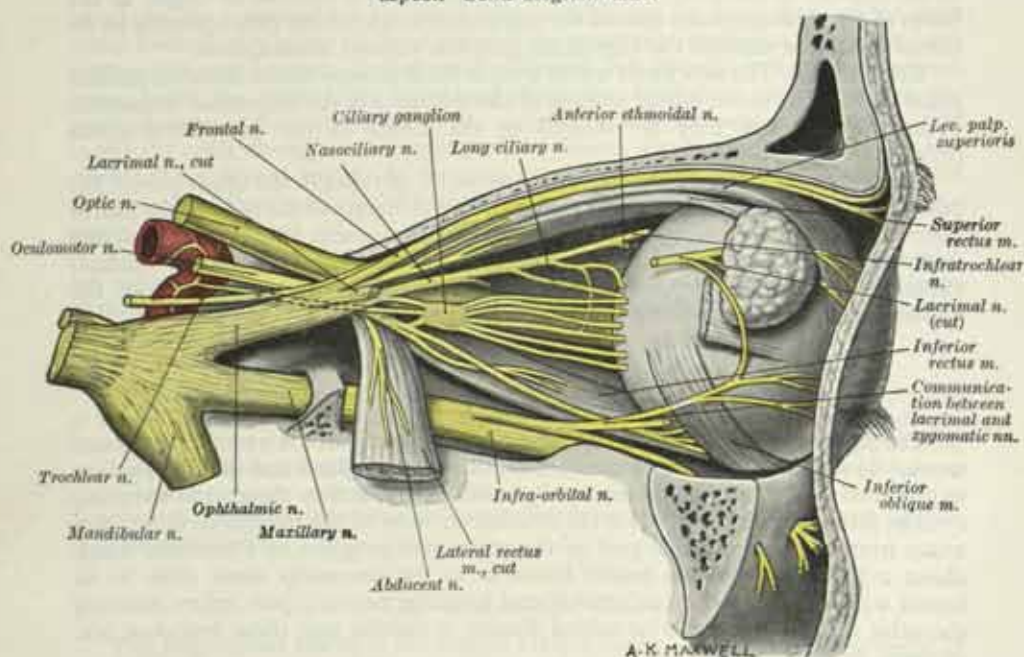
† See footnote p. 1097.

maticotemporal branch of the maxillary nerve. Sometimes the latter branch is absent and is replaced by a branch of the lacrimal nerve.

The **frontal nerve** (figs. 933, 934) is the largest branch of the ophthalmic nerve. It enters the orbit through the superior orbital fissure above the muscles, and runs forwards between the levator palpebræ superioris and the periosteum. About midway between the apex and base of the orbit it divides into a small supratrochlear and a large supra-orbital branch.

The **supratrochlear nerve** runs medially and forwards, passes above the pulley of the obliquus superior, and gives off a descending filament to join the infratrochlear branch of the nasociliary nerve. The nerve then emerges from the orbit between the pulley of the obliquus superior and the supra-orbital foramen, curves upwards on the forehead close to the bone in company with the supratrochlear branch of the ophthalmic artery, and sends filaments to the conjunctiva and skin of the upper eyelid; it then ascends under cover of the corrugator and the frontal belly of the

FIG. 934.—The nerves of the right orbit, and the ciliary ganglion. Lateral aspect. Semi-diagrammatic.



occipitofrontalis and divides into branches which pierce these muscles and supply the skin of the lower part of the forehead close to the median plane.

The **supra-orbital nerve** runs forwards between the levator palpebræ superioris and the roof of the orbit, passes through the supra-orbital notch or foramen, and gives off palpebral filaments to the upper eyelid and conjunctiva. It then ascends upon the forehead with the supra-orbital artery, and divides into a smaller medial and a larger lateral branch, which supply the skin of the scalp, reaching nearly as far back as the lambdoid suture. These two branches are at first situated deep to the frontal belly of the occipitofrontalis; the medial branch perforates this muscle, the lateral branch pierces the epicranial aponeurosis. Both branches supply small twigs to the mucous membrane of the frontal sinus and to the pericranium.

The **nasociliary nerve** (figs. 933, 934) is intermediate in size between the frontal and lacrimal nerves, and is more deeply placed. It enters the orbit through the medial part of the superior orbital fissure within the annulus tendineus, which gives origin to the recti muscles of the eyeball, and here it is situated between the two rami of the oculomotor nerve. It crosses the optic nerve with the ophthalmic artery, and runs obliquely below the rectus superior and obliquus superior, to the medial wall of the orbital cavity. Here, under the name of the **anterior ethmoidal**

nerve, it passes through the anterior ethmoidal foramen and canal and, entering the cavity of the cranium, runs forwards in a shallow groove on the upper surface of the cribriform plate of the ethmoid bone, beneath the dura mater; it then descends through a slit at the side of the crista galli into the nasal cavity, and lies in a groove on the inner surface of the nasal bone. It supplies two *internal nasal branches*—a medial to the mucous membrane of the front part of the nasal septum, and a lateral to the anterior part of the lateral wall of the nasal cavity. Finally it emerges, as the *external nasal branch*, at the lower border of the nasal bone, and, passing down under cover of the compressor naris muscle, supplies the skin of ala, the apex and the vestibule of the nose.

The nasociliary nerve receives a communicating branch from the ciliary ganglion, and gives off the long ciliary, the infratrochlear and the posterior ethmoidal nerves.

The *ramus communicans with the ciliary ganglion* (p. 1097) usually joins the nasociliary nerve as the latter enters the orbital cavity. It lies on the lateral side of the optic nerve, and emerges from the posterosuperior angle of the ciliary ganglion (fig. 932); it is sometimes joined by a filament from the internal carotid plexus of the sympathetic, or from the superior ramus of the oculomotor nerve.

The *long ciliary nerves*, two or three in number, are given off from the nasociliary nerve, as it crosses the optic nerve. They accompany the short ciliary nerves from the ciliary ganglion, pierce the sclera near the attachment of the optic nerve, and, running forwards between the sclera and the choroid, are distributed to the ciliary body, iris and cornea. They usually contain the sympathetic fibres for the dilatator pupillæ muscle (p. 1097); these are postganglionic fibres and have their cells of origin in the superior cervical ganglion.

The *infratrochlear nerve* is given off from the nasociliary nerve near the anterior ethmoidal foramen. It runs forwards along the medial wall of the orbit above the upper border of the rectus medialis, and is joined, near the pulley of the obliquus superior, by a filament from the supratrochlear nerve. It then escapes from the orbit below the pulley of the obliquus superior; it supplies branches to the skin of the eyelids and side of the nose above the medial angle of the eye, the conjunctiva, lacrimal sac and caruncula lacrimalis.

The *posterior ethmoidal nerve* leaves the orbital cavity through the posterior ethmoidal foramen and gives twigs to the ethmoidal and sphenoidal sinuses. This nerve is absent in about thirty per cent. of subjects.

THE MAXILLARY NERVE (figs. 934, 935)

The **maxillary nerve**, or second division of the trigeminal nerve, is a sensory nerve, and is intermediate in position and size between the ophthalmic and mandibular nerves. It begins at the middle of the trigeminal ganglion as a flattened plexiform band, and, passing horizontally forwards along the lower part of the lateral wall of the cavernous sinus (fig. 941), leaves the skull through the foramen rotundum, where it becomes more cylindrical in form and firmer in texture. It then crosses the upper part of the pterygopalatine fossa, inclines laterally on the posterior surface of the orbital process of the palatine bone and on the upper part of the posterior surface of the maxilla, and enters the orbit through the inferior orbital fissure. It is now named the **infra-orbital nerve** and, having traversed the infra-orbital groove and canal in the floor of the orbit, it appears on the face through the infra-orbital foramen. At its termination the nerve lies under cover of the levator labii superioris, and divides into branches which are distributed to the side of the nose, the lower eyelid, the skin and mucous membrane of the cheek and upper lip, and join with filaments of the facial nerve.

In view of the fact that the mouth is generally regarded as representing a pair of fused visceral clefts, the maxillary nerve can be described as the pretrematic and the mandibular nerve as the post-trematic branch of the trigeminal nerve. The maxillary nerve supplies the structures derived from the maxillary process, which extends over some of the structures developed from the median nasal process and its fused globular (premaxillary) processes (p. 112).

The *branches of the maxillary nerve* may be divided into four groups, according

as they are given off in the cranium, in the pterygopalatine fossa, in the infra-orbital canal, or on the face.

In the cranium	Meningeal.
In the pterygopalatine fossa	{ Ganglionic. Zygomatic. Posterior superior alveolar (dental)
In the infra-orbital canal	{ Middle superior alveolar (dental) Anterior superior alveolar (dental)
On the face	{ Palpebral. Nasal. Labial.

The **meningeal nerve** is given off from the maxillary nerve near the trigeminal ganglion; it accompanies the anterior branch of the middle meningeal artery and supplies the dura mater of the middle cranial fossa.

The **ganglionic branches**, two in number, connect the maxillary nerve to the pterygopalatine (sphenopalatine) ganglion, which lies immediately below it in the pterygopalatine fossa (fig. 935). They contain the secreto-motor fibres for the lacrimal gland (*vide infra*), and sensory fibres from the orbital periosteum and the mucous membranes of the nose, palate and pharynx (p. 1106).

The **zygomatic nerve** (fig. 935) arises in the pterygopalatine fossa, enters the orbit by the inferior orbital fissure, courses along the lateral wall of the orbit, and divides into two branches, zygomaticotemporal and zygomaticofacial.

The **zygomaticotemporal branch** runs along the lateral wall of the orbit, sends a branch to join the lacrimal nerve (p. 1101), and, passing through a canal in the zygomatic bone, enters the temporal fossa. It ascends between the bone and the temporalis muscle, pierces the temporal fascia about 2 cm. above the zygomatic arch, and is distributed to the skin of the temple. It communicates with the facial nerve and with the auriculotemporal branch of the mandibular nerve. As it pierces the temporal fascia, it sends a slender twig between the two layers of the fascia towards the lateral angle of the eye. The communication with the lacrimal nerve conveys parasympathetic postganglionic fibres from the pterygopalatine ganglion to the lacrimal gland.

The **zygomaticofacial branch** passes along the inferolateral border of the orbit, emerges upon the face through a foramen in the zygomatic bone, and, perforating the orbicularis oculi, supplies the skin on the prominence of the cheek. It forms a fine plexus with the zygomatic branches of the facial nerve and the palpebral branches of the maxillary nerve.

The **superior alveolar (dental) branches** (fig. 935) arise from the maxillary nerve before it leaves the pterygopalatine fossa, or as it lies in the infra-orbital groove canal they are termed the posterior, the middle and the superior alveolar (dental) branches.

The **posterior superior alveolar (dental) nerve** arises from the maxillary in the pterygopalatine fossa and runs downwards and forwards to pierce the infra-temporal surface of the maxilla (fig. 342) and descend under the mucous lining of the maxillary sinus. After supplying the sinus the nerve divides into small branches which link up to constitute the molar part of the *superior dental plexus* and supply twigs to the molar teeth. In addition, it supplies a branch to the upper gum and the adjoining part of the cheek.

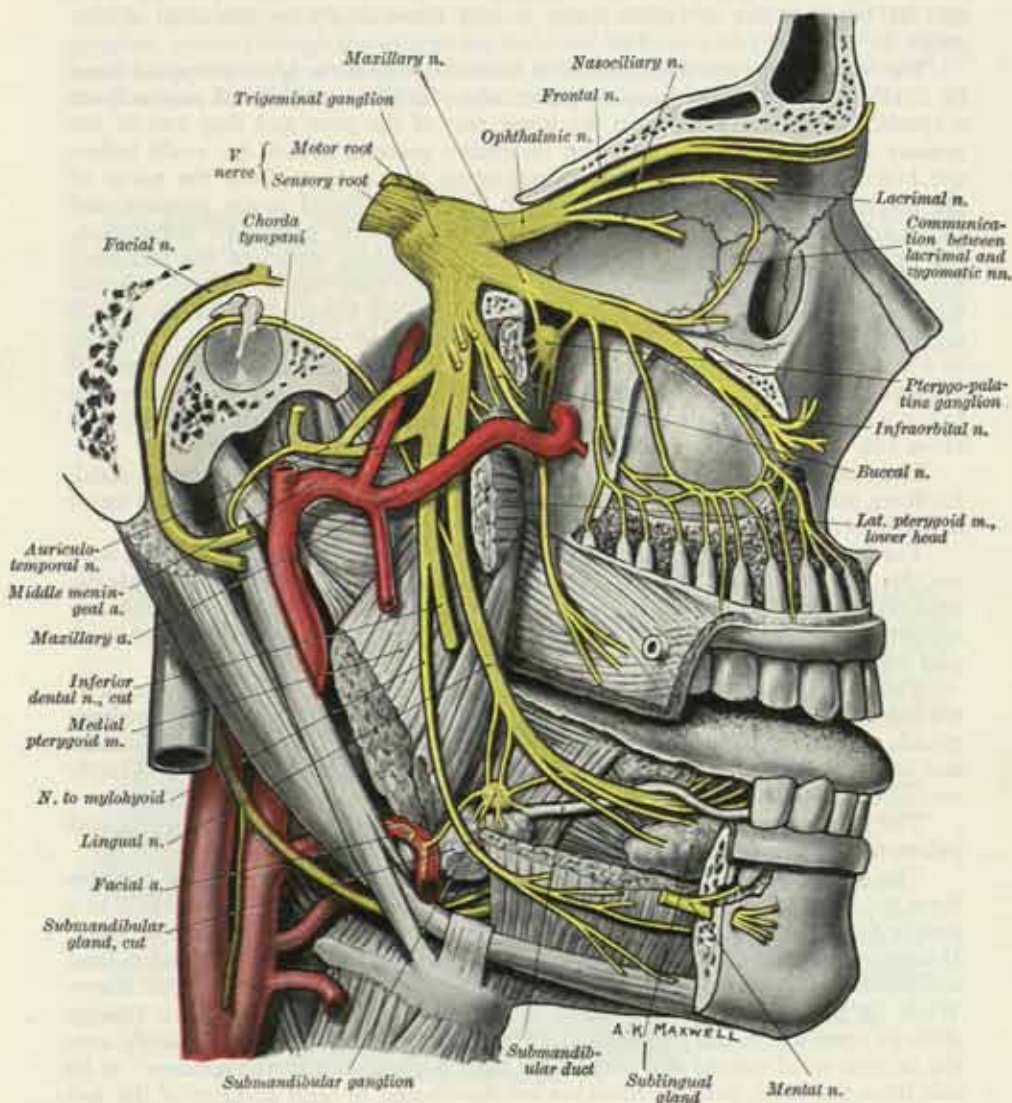
The **middle superior alveolar (dental) nerve** arises from the maxillary as it passes along the infra-orbital groove, and runs downwards and forwards in the lateral wall of the maxillary sinus. Like the posterior, it terminates in a number of small branches which link up with the superior dental plexus, and these give off twigs to supply the upper premolar teeth. This nerve is variable in its behaviour. It may be duplicated or triplicated or it may be absent.*

The **anterior superior alveolar (dental) branch** (fig. 935) leaves the lateral side of the infra-orbital nerve near the midpoint of the infra-orbital canal, and runs

* F. Wood Jones, *J. Anat.* 73, 1939; M. J. T. Fitzgerald, *J. Anat.*, 90, 1956.

in the canalis sinuosus (p. 342) in the anterior wall of the maxillary sinus. At first it curves beneath the infra-orbital foramen and passes medially towards the nose; it then turns downwards and divides into branches which supply the incisor and canine teeth. It takes part in the formation of the superior dental plexus, and gives off a *nasal branch*, which passes through a minute canal in the lateral wall of the inferior meatus, and supplies the mucous membrane of the anterior part of the lateral wall (as high as the opening of the maxillary sinus) and the floor of the nasal

FIG. 935.—The right maxillary and mandibular nerves, and the submandibular ganglion. Semi-diagrammatic.



cavity, communicating with the nasal branches from the pterygopalatine ganglion. Its terminal branch emerges near the root of the anterior nasal spine and supplies the adjoining part of the nasal septum.

The **palpebral branches** ascend deep to the orbicularis oculi. They soon pierce the muscle to supply the skin of the lower eyelid, and join with the facial and zygomaticofacial nerves near the lateral angle of the eye.

The **nasal branches** supply the skin of the side of the nose and of the movable part of the nasal septum, and join with the external nasal branch of the anterior ethmoidal nerve.

The **labial branches** are large and numerous; they descend behind the levator labii superioris, and supply the skin of the anterior part of the cheek, the skin of the upper lip, the mucous membrane of the mouth, and the labial glands. They are joined by branches from the facial nerve, and form with them the *infra-orbital plexus*.

The **pterygopalatine (sphenopalatine) ganglion** (figs. 935, 937) is the largest of the peripheral ganglia of the parasympathetic system. It is deeply placed in the pterygopalatine fossa, close to the sphenopalatine foramen and in front of the pterygoid canal. It is somewhat flattened, of a reddish-grey colour, and is situated just below the maxillary nerve as it crosses the fossa. Although it is *connected functionally with the facial nerve*, its topographical relations with the maxillary nerve and its branches are so intimate that it may conveniently be described at this stage.

The *motor or parasympathetic root* is formed by the *nerve of the pterygoid canal* (p. 1118), which enters the ganglion posteriorly. Its fibres are believed to arise from a special lacrimatory nucleus in the lower part of the pons and they run in the sensory root of the facial nerve and its greater petrosal branch (p. 1118) before the latter unites with the deep petrosal nerve (fig. 917) to form the nerve of the pterygoid canal. These preganglionic fibres are relayed in the ganglion and the postganglionic fibres follow a complicated course to gain their destination. Leaving the ganglion in one of the ganglionic branches, they join the maxillary nerve and pass into its zygomatic branch. Thence they run in the zygomatico-temporal nerve and later leave it in the communicating branch by which it is connected to the lacrimal nerve (p. 1104). In this way they reach the lacrimal gland, to which they supply secreto-motor fibres. In addition, secreto-motor fibres—of uncertain origin—for the palatine, pharyngeal and nasal glands are believed to follow a similar route to the ganglion, where they are relayed. Their postganglionic fibres run in the palatine and nasal branches of the ganglion (fig. 937).

The *sympathetic root* is also incorporated in the nerve of the pterygoid canal. Its fibres, which are postganglionic, arise in the superior cervical ganglion and travel in the internal carotid plexus and the deep petrosal nerve.

The *branches* which appear to arise from the pterygopalatine ganglion (fig. 936) are, for the most part, derived from the maxillary nerve through its ganglionic branches, and, though intimately related to the ganglion, *do not establish any synaptic connexions with its cells*. They include orbital, palatine, nasal and pharyngeal branches.

The *orbital branches* are two or three delicate filaments which enter the orbit by the inferior orbital fissure, and are distributed to the periosteum and the orbitalis muscle; some twigs pass through the posterior ethmoidal foramen to the sphenoidal and ethmoidal sinuses. The fibres which supply the orbitalis muscle are directly continuous with the fibres of the sympathetic root of the ganglion.

The *palatine nerves* (fig. 936) are distributed to the roof of the mouth, the soft palate, the tonsil, and the lining membrane of the nasal cavity.

The *greater palatine nerve* descends through the greater palatine canal, emerges upon the hard palate through the greater palatine foramen, and runs forwards in a groove on the inferior surface of the bony palate, nearly as far as the incisor teeth. It supplies the gums, and the mucous membrane and glands of the hard palate, and communicates in front with terminal filaments of the long sphenopalatine nerve. While in the greater palatine canal, it gives off *nasal branches*, which emerge through openings in the perpendicular plate of the palatine bone, and ramify over the inferior nasal concha and the walls of the middle and inferior meatuses; at its exit from the canal, palatine branches are distributed to both surfaces of the soft palate.

The *lesser palatine nerves* descend through the greater palatine canal, emerge through the lesser palatine foramina and supply branches to the uvula, tonsil and soft palate. The fibres conveying taste impulses from the palate probably pass *via* the palatine nerves to the pterygopalatine ganglion and thence, without interruption, *via* the nerve of the pterygoid canal and the greater petrosal nerve to the facial ganglion, where their cells of origin are situated. The central processes of these cells pass through the sensory root of the facial nerve to reach the nucleus of the tractus solitarius (p. 954).

The *nasal branches* comprise the long and short sphenopalatine nerves, which

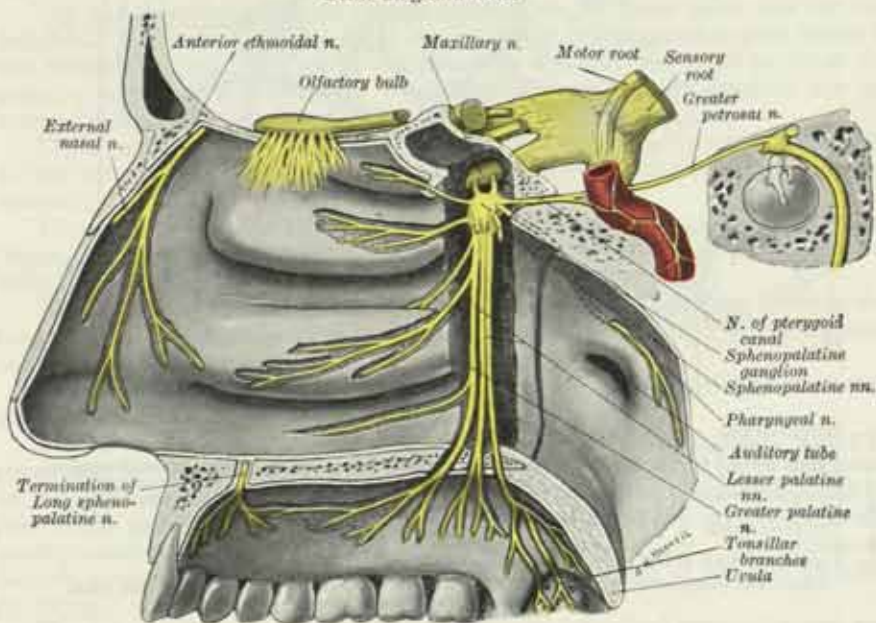
enter the nasal cavity through the sphenopalatine foramen. The *long sphenopalatine nerve* crosses the roof of the nasal cavity below the orifice of the sphenoidal sinus, and then runs obliquely downwards and forwards on the posterior part of the nasal septum, lying in a groove on the vomer. It descends to the roof of the mouth through the incisive canal, and communicates with the corresponding nerve of the opposite side and with the greater palatine nerve. It furnishes a few filaments to the mucous membrane of the nasal septum and the posterior part of the roof of the nasal cavity, and ends by supplying a large part of the mucous membrane of the hard palate. The *short sphenopalatine nerves* supply the mucous membrane covering the superior and middle nasal conchæ, the lining of the posterior ethmoidal sinuses and the posterior part of the nasal septum.

The *pharyngeal nerve*, a small branch, arises from the posterior part of the ganglion, passes through the palatinovaginal canal with the pharyngeal branch of the maxillary artery, and is distributed to the mucous membrane of the nasal part of the pharynx, behind the auditory tube.

THE MANDIBULAR NERVE (figs. 935, 939)

The **mandibular nerve** supplies the teeth and gums of the mandible, the skin of the temporal region, part of the auricle, the lower lip, the lower part of the face, and the muscles of mastication; it also supplies the mucous membrane of the anterior two-thirds of the tongue and the floor of the mouth. It is the largest division of the trigeminal nerve, and is made up of two roots: a large, sensory root, which proceeds from the lateral part of the trigeminal ganglion and emerges almost

FIG. 936.—The right pterygopalatine ganglion and its branches. Semi-diagrammatic.

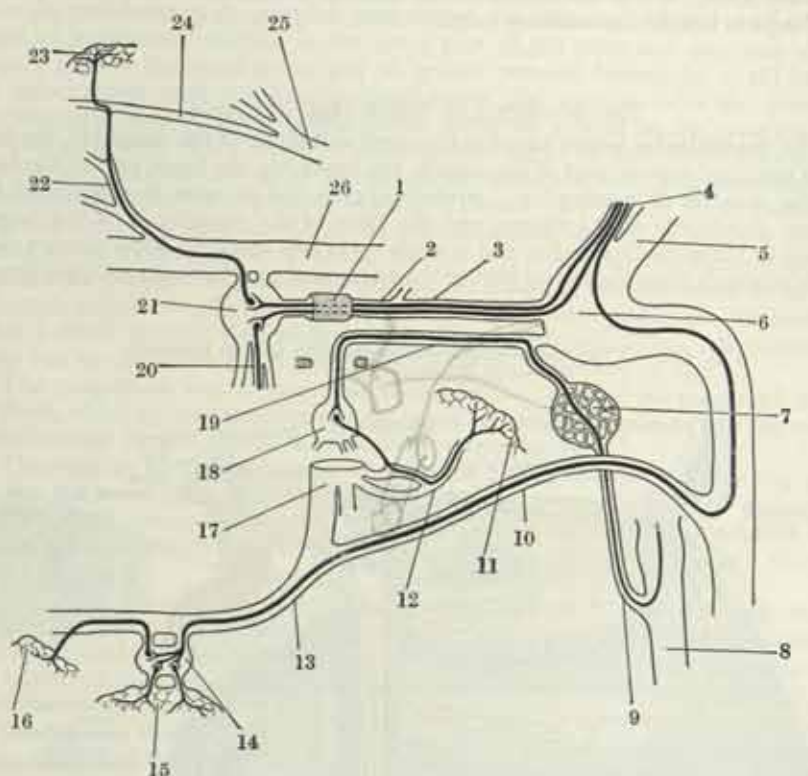


immediately through the foramen ovale of the sphenoid bone; and a small motor root (the motor part of the trigeminal) which passes below the ganglion, and unites with the sensory root, just outside the foramen ovale, where the nerve lies between the tensor veli palatini muscle medially and the lateral pterygoid laterally. Immediately beyond the junction of the two roots the nerve sends off from its medial side the nervous spinosus and the nerve to the medial pterygoid muscle, and then divides into a small anterior and a large posterior trunk. As it descends from the foramen ovale, the mandibular nerve lies at a depth of 4 cm. from the surface and a little in front of the neck of the mandible.

The **nervus spinosus** enters the skull through the foramen spinosum with the middle meningeal artery. It divides into two branches, anterior and posterior, which accompany the main divisions of the artery and supply the dura mater; the posterior branch also supplies a twig to the mucous lining of the mastoid air-cells; the anterior communicates with the meningeal branch of the maxillary nerve.

The **nerve to the medial pterygoid muscle** is a slender branch which enters the deep surface of the muscle; it gives one or two filaments which pass through the otic ganglion (p. 1130) *without being interrupted* and emerge from it to supply the tensor tympani and tensor veli palatini muscles (fig. 939).

FIG. 937.—A diagram to show the parasympathetic connexions of the pterygo-palatine, otic and submandibular ganglia. The parasympathetic fibres, both pre- and postganglionic, are shown as heavy black lines.



- | | | |
|------------------------------|-----------------------------------|--------------------------------|
| 1. Pterygoid canal. | 10. Chords tympani n. | 19. Lesser petrosal n. |
| 2. Nerve of pterygoid canal. | 11. Parotid gland. | 20. Palatine nn. |
| 3. Greater petrosal n. | 12. Auriculo-temporal n. | 21. Pterygo-palatine ganglion. |
| 4. Sensory root of VII. | 13. Lingual n. | 22. Zygomaticotemporal n. |
| 5. Motor root of VII. | 14. Submandibular ganglion. | 23. Lacrimal gland. |
| 6. Ganglion of VII. | 15. Submandibular salivary gland. | 24. Lacrimal n. |
| 7. Tympanic plexus. | 16. Sublingual salivary gland. | 25. Ophthalmic n. |
| 8. IX. | 17. Mandibular n. | 26. Maxillary n. |
| 9. Tympanic branch of IX. | 18. Otic ganglion. | |

Note.—The parasympathetic fibres in the palatine nerves (20) are secretomotor to the nasal, palatine and pharyngeal glands.

The *small anterior trunk* of the mandibular nerve gives off (*a*) a sensory branch named the buccal nerve, and (*b*) motor branches, viz. the masseteric, deep temporal and lateral pterygoid nerves.

The **buccal nerve** (fig. 938) passes forwards between the two heads of the lateral pterygoid, and then downwards beneath or through the lower part of the temporal muscle; it emerges from under cover of the ramus of the mandible and the anterior border of the masseter, and unites with the buccal branches of the facial nerve. It furnishes a branch to the lateral pterygoid during its passage through that muscle, and may give off the anterior deep temporal nerve. The buccal nerve supplies the skin over the anterior part of the buccinator muscle, and the mucous

membrane lining its inner surface and the posterior part of the buccal surface of the gum.

The **masseteric nerve** (fig. 938) passes laterally, above the lateral pterygoid, in front of the temporomandibular articulation, and behind the tendon of the temporal muscle; it crosses the posterior part of the mandibular notch with the masseteric artery, ramifies in the deep surface of the masseter, and gives a filament to the joint.

The **deep temporal nerves** are usually two in number, anterior and posterior. They pass above the upper border of the lateral pterygoid and enter the deep surface of the temporal muscle. The *posterior branch*, of small size, is placed at the posterior part of the temporal fossa, and sometimes arises in common with the masseteric nerve. The *anterior branch* is frequently given off from the buccal nerve, and then ascends over the upper head of the lateral pterygoid. A third, or middle, branch is often present.

The **nerve to the lateral pterygoid** enters the deep surface of the muscle. It may arise separately from the anterior division of the mandibular nerve, or in conjunction with the buccal nerve.

The large *posterior trunk* of the mandibular nerve is for the most part sensory, but receives a few filaments from the motor root. It divides into auriculotemporal, lingual and inferior alveolar (dental) nerves.

The **auriculotemporal nerve** generally arises by two roots, which encircle the middle meningeal artery (fig. 935). It runs backwards under cover of the lateral pterygoid on the surface of the tensor veli palatini and passes between the sphenomandibular ligament and the neck of the mandible. It then passes laterally behind the temporomandibular joint in relationship with the upper part of the parotid gland. Finally, emerging from behind the joint, it ascends, posterior to the superficial temporal vessels, over the posterior root of the zygoma, and divides into superficial temporal branches.

The auriculotemporal nerve communicates with the facial nerve and the otic ganglion. The branches to the facial nerve, usually two in number, pass forwards and laterally behind the neck of the mandible and join the facial nerve at the posterior border of the masseter. The filaments from the otic ganglion join the roots of the auriculotemporal nerve close to their origin (fig. 944).

The *branches* of the auriculotemporal nerve are the anterior auricular, branches to the external acoustic (auditory) meatus, articular, parotid and superficial temporal.

The *auricular branches* are usually two in number: they supply the skin of the tragus (fig. 940) and, sometimes, a small part of the adjoining portion of the helix.

The *branches to the external acoustic meatus*, two in number, pass between the bony and cartilaginous parts of the meatus, and supply the skin of the meatus; the upper one sends a twig to the tympanic membrane.

The *articular branches* consist of one or two twigs which enter the posterior part of the temporomandibular joint.

The *parotid branches* convey secretomotor fibres to the parotid gland. The pre-ganglionic fibres are originally derived from the glossopharyngeal nerve and travel by the lesser petrosal nerve to the otic ganglion whence the postganglionic fibres pass to the auriculotemporal nerve and so reach the gland (fig. 937). They also convey vasomotor fibres to the blood-vessels of the parotid gland. These fibres are directly continuous with the fibres of the sympathetic root of the otic ganglion (p. 1130).

The *superficial temporal branches* accompany the superficial temporal artery and its terminal branches; they supply the skin of the temporal region and communicate with the facial and zygomaticotemporal nerves.

The **lingual nerve** (fig. 935) is sensory to the mucous membrane of the anterior two-thirds of the tongue, and to the floor of the mouth and the mandibular gums.

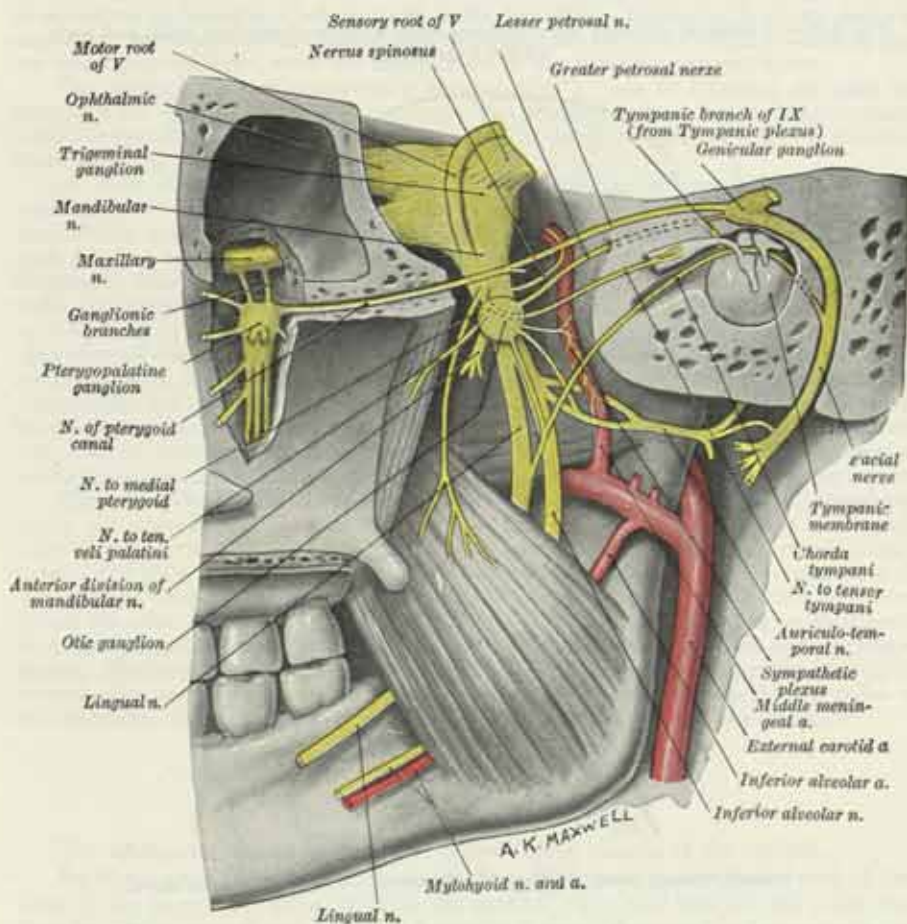
It arises from the posterior division of the mandibular nerve, and lies at first between the tensor veli palatini and the lateral pterygoid muscle, where it is joined by the chorda tympani branch of the facial nerve, and frequently by a branch of the inferior alveolar nerve. Emerging from under cover of the lateral pterygoid muscle the lingual nerve proceeds downwards and forwards between the ramus of the man-

The **inferior alveolar (dental) nerve** descends deep to the lateral pterygoid muscle, and then, at the lower border of the muscle, it passes between the sphenomandibular ligament and the ramus of the mandible to the mandibular foramen. Here it enters the mandibular canal, and runs below the teeth as far as the mental foramen, where it divides into an incisive and a mental branch. Below the lateral pterygoid muscle the nerve is accompanied by the inferior alveolar artery.

The inferior alveolar nerve gives off the mylohyoid nerve, branches to the molar and premolar teeth of the mandible, the incisive and the mental nerves.

The **mylohyoid nerve** is derived from the inferior alveolar nerve just before the latter enters the mandibular foramen. It pierces the sphenomandibular ligament, descends in a groove on the medial surface of the ramus of the mandible and,

FIG. 939.—The right otic ganglion and its branches displayed from the medial side. Semi-diagrammatic.



passing below the mylohyoid line, it reaches the under surface of the mylohyoid muscle, which it supplies together with the anterior belly of the digastric.

The branches to the molar and premolar teeth supply the adjoining gum also. Before they enter the roots of the teeth they communicate with one another and form an inferior dental plexus.

The **incisive branch** is continued onwards within the bone and supplies the canine and incisor teeth.*

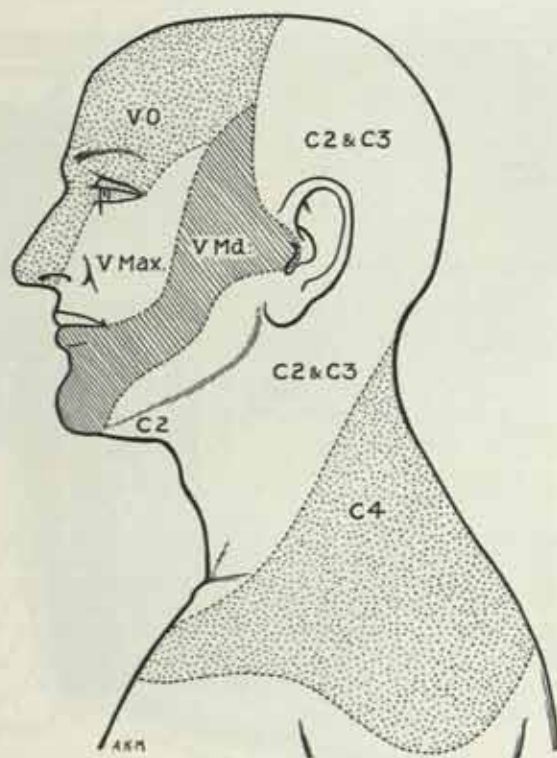
* According to C. Starkie and D. Stewart (*J. Anat.*, 65, 1931), the nerves which supply the incisor teeth form an elaborate plexus on the external aspect of the mandible after emerging from the mental foramen and before they re-enter the bone. The canine tooth may be supplied either from the incisor plexus or from the plexus which innervates the premolars.

The *mental nerve* emerges at the mental foramen, and divides beneath the depressor anguli oris muscle into three branches; one descends to the skin of the chin, and two ascend to the skin and mucous membrane of the lower lip; these branches communicate freely with the facial nerve (mandibular branch).

The mandibular nerve is distributed to the structures derived from the mandibular arch, and represents the post-trematic branch of the trigeminal nerve. The connexion of the nerve with the arch is indicated by: (1) its close relationship to the sphenomandibular ligament and the mandible; (2) its distribution to the anterior portion of the tongue; (3) its distribution to the tragus and the tympanic membrane; and (4) its union with the pretrematic nerve of the hyomandibular cleft, viz. the chorda tympani branch of the facial nerve.

Applied Anatomy.—A lesion of the whole trigeminal nerve causes anæsthesia of the corresponding anterior half of the scalp, of the face (excepting a small area near the

FIG. 940.—A diagram showing the cutaneous nerve-supply of the face, scalp and neck.
(After Foerster.)



V O=Ophthalmic nerve; V Max.=Maxillary nerve; V Md.=Mandibular nerve.

angle of the mandible supplied by the great auricular nerve), of the cornea and conjunctiva, and of the mucous membranes of the nose, mouth and anterior half of the tongue. Paralysis and atrophy occur in the muscles supplied by the nerve and, when the mouth is opened the mandible is thrust over to the paralysed side. Lesions of the divisions of the nerve give a more limited sensory loss and, if affecting the lingual nerve below the point at which it is joined by the chorda tympani, will be accompanied by permanent loss of taste in the corresponding half of the anterior part of the tongue.*

Referred pain in the trigeminal nerve.—Pains referred to various branches of the

* Wilfred Harris (*B.M.J.* i. 1952) has reviewed a large number of cases of lesions of the trigeminal nerve, many of which he has followed for a number of years. He has found that lesions causing loss of general sensibility (tactile, painful and thermal) in the palate and anterior half of the tongue are almost invariably associated with loss of taste. In lesions due to surgical operations on the nerve, its ganglion or its sensory root, the loss of taste is immediate but it usually recovers after a period which varies from a few hours in some cases to

trigeminal nerve are of very frequent occurrence. As a general rule the diffusion of pain over the various branches of the nerve is at first confined to one only of the main divisions, although in severe cases pain may radiate over the branches of the other main divisions. The commonest example, of this condition is the neuralgia which is so often associated with dental caries—here, although the tooth itself may not appear to be painful, the most distressing referred pains may be experienced, and these are at once relieved by treatment directed to the affected tooth.

Many other examples of trigeminal referred pain could be quoted, but it will be sufficient to mention the more common ones. In the area of the ophthalmic nerve, severe supra-orbital pain is commonly associated with acute glaucoma or with frontal or ethmoidal sinusitis. Malignant growths or empyema of the maxillary sinus, or unhealthy conditions about the inferior conchæ or the septum of the nose, are often found giving rise to 'second division' neuralgia, and should be always looked for in the absence of dental disease in the maxilla. It is in the mandibular nerve, however, that some of the most striking examples are seen. It is quite common to meet with patients who complain of pain in the ear, in whom there is no sign of aural disease, and the cause is usually to be found in a carious tooth in the mandible. Moreover, with an ulcer or cancer of the tongue, often the first pain to be experienced is one which radiates to the ear and temporal fossa, over the distribution of the auriculotemporal nerve.

The lingual nerve is occasionally divided with a view to relieving the pain in cancer of the tongue. This may be carried out where the nerve lies in direct contact with the mandible below and behind the last molar tooth, covered only by the mucous membrane (p. 1110).

In cases of intractable neuralgia of the trigeminal nerve various operative procedures have been introduced from time to time. The trunks of the maxillary and mandibular nerves and the trigeminal ganglion itself have been injected with alcohol with varying degrees of success, and excision of the ganglion, in whole or in part, has frequently been performed successfully, but the last-named operation involves serious risks (laceration of the cavernous sinus, etc.) and is now rarely undertaken. The sensory root of the nerve may be divided behind the ganglion and this is now the operation of election when the pain is confined to the maxillary and mandibular nerve areas (fig. 940). Complete division of the sensory root necessarily denervates the cornea completely and the resulting loss of the corneal reflex leads to neuropathic keratitis. Consequently, in these cases an endeavour is made to preserve the ophthalmic fibres, which lie in the upper and medial part of the root and can be spared if the incision is restricted to the lower and lateral fibres. The motor root of the nerve is left intact.

When the pain is limited to the ophthalmic area or to the ophthalmic and maxillary areas, the operation of election* consists in the division of the fibres of the spinal tract of the nerve, where it is most superficial (p. 953) and sometimes forms a recognisable elevation (p. 824) between the lateral margin of the fasciculus cuneatus and the posterior border of the lower part of the olive. Section of the tract 4-5 mm. below the obex preserves all, or nearly all, of the mandibular fibres, as, at this level, they have already entered the upper portion of the nucleus of the tract and so escape injury. Following the operation painful and thermal sensibility are lost over the ophthalmic and maxillary areas, *but tactile sensibility is retained and the corneal reflex is not abolished.* The operation preferably is conducted under local anaesthesia.*

THE ABDUCENT NERVE (fig. 934)

The **abducent nerve** supplies the lateral rectus muscle of the eyeball.

Its fibres arise from a small nucleus which is situated in the upper part of the floor of the fourth ventricle, close to the median plane and beneath the colliculus facialis. They pass downwards and forwards through the pons, and emerge in the furrow between the lower border of the pons and the upper end of the pyramid of the medulla oblongata (fig. 824).

The **nucleus** of the abducent nerve represents the somatic efferent column and retains its primitive position close to the median plane (p. 965).

Connexions.—The nucleus of the abducent nerve receives fibres from: (1) the pyramidal tract of the opposite side; (2) the medial longitudinal bundle, by which it is connected with the nuclei of the eighth cranial nerve; and (3) the tectobulbar

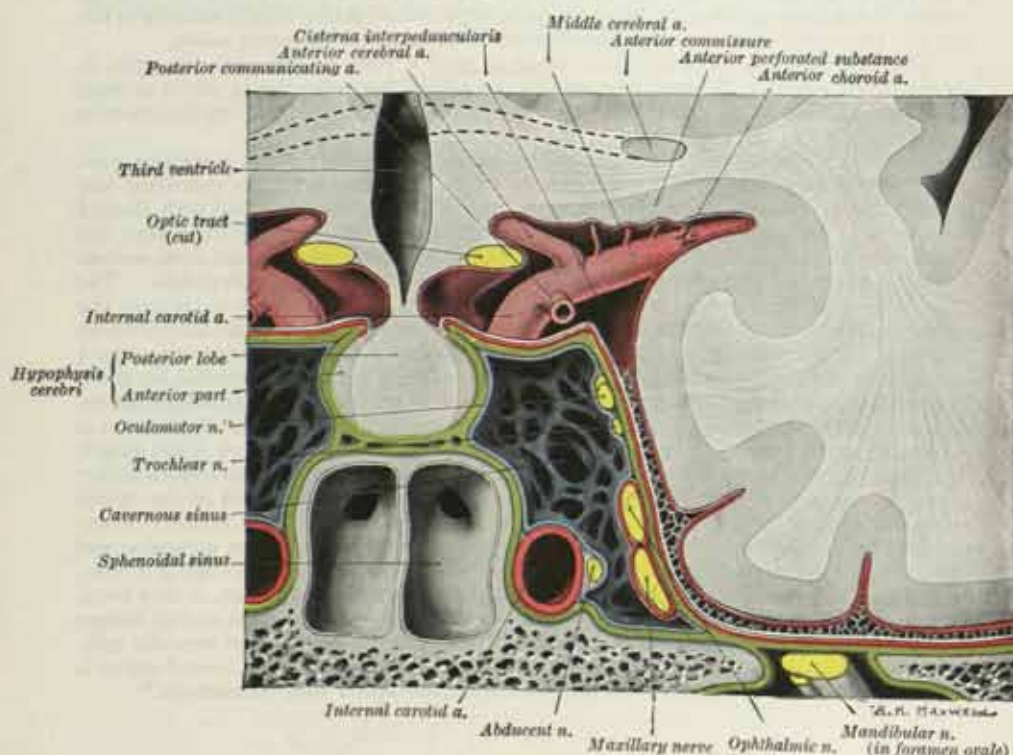
months and even years in others. He does not believe that the immediate after results of surgical interference indicate that any fibres conveying gustatory sensibility reach the central nervous system through the sensory root of V, but he has come to the conclusion that the presence of general sensibility in the palate and the anterior half of the tongue plays an important part in connexion with the recognition and appreciation of taste stimuli.

* Murray A. Falconer, *J. Neurol., Neurosurg., and Psychiat.*, 12, 1949.

tract, by which it is connected with the visual cortex through the medium of the superior colliculus.

Course.—After leaving the surface of the brain-stem, the abducent nerve runs upwards, forwards and laterally through the cisterna pontis, and usually dorsal to the anterior inferior cerebellar artery. It pierces the dura mater lateral to the dorsum sellæ of the sphenoid bone and then bends sharply forwards as it crosses the superior border of the petrous part of the temporal bone close to its apex. In this situation it passes below the petrosphenoidal ligament—a fibrous band which connects the lateral margin of the dorsum sellæ to the upper border of the petrous part of the temporal bone near its medial end. It next traverses the cavernous sinus, lying at first lateral and then inferolateral to the internal carotid artery, and enters the

FIG. 941.—An obliquely coronal section through the middle cranial fossa. The ophthalmic and maxillary nerves are shown surrounded by the forward extension of the *cavum trigeminale* (p. 1081).



orbital cavity through the medial part of the superior orbital fissure. It passes within the common tendinous ring from which the recti muscles of the eyeball arise, lying below and lateral to the oculomotor and nasociliary nerves, and finally sinks into the ocular surface of the lateral rectus.

In the cavernous sinus the abducent nerve is joined by several filaments from the internal carotid plexus, and communicates with the ophthalmic nerve.*

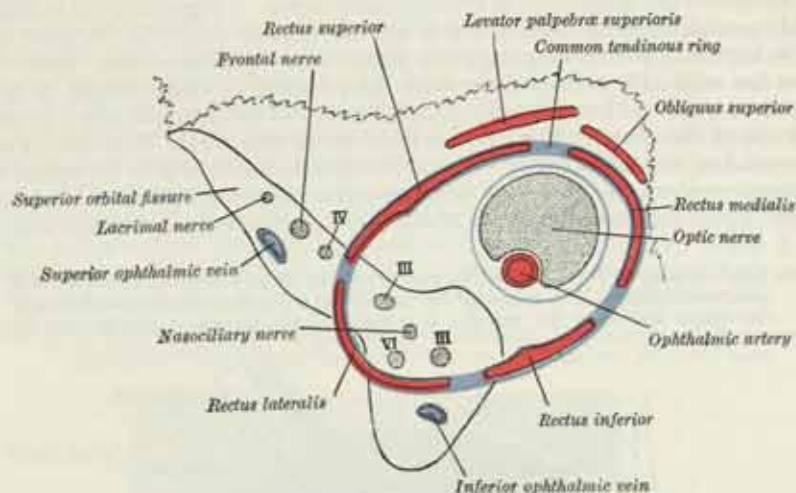
Applied Anatomy.—The abducent nerve is occasionally involved in fractures of the base of the skull. The result of paralysis of this nerve is medial or convergent squint. Diplopia is also present.

THE FACIAL NERVE (figs. 944 to 948)

The **facial nerve** possesses a motor and a sensory root (fig. 824). The two roots appear at the lower border of the pons just lateral to the recess between the olive and

* See footnote p. 1097.

FIG. 942.—Scheme to show the common tendinous ring, the origins of the recti, and the relative positions of the nerves entering the orbital cavity through the superior orbital fissure. (Modified from a figure in Whitnall's *Anatomy of the Human Orbit*; Oxford Medical Publications.)

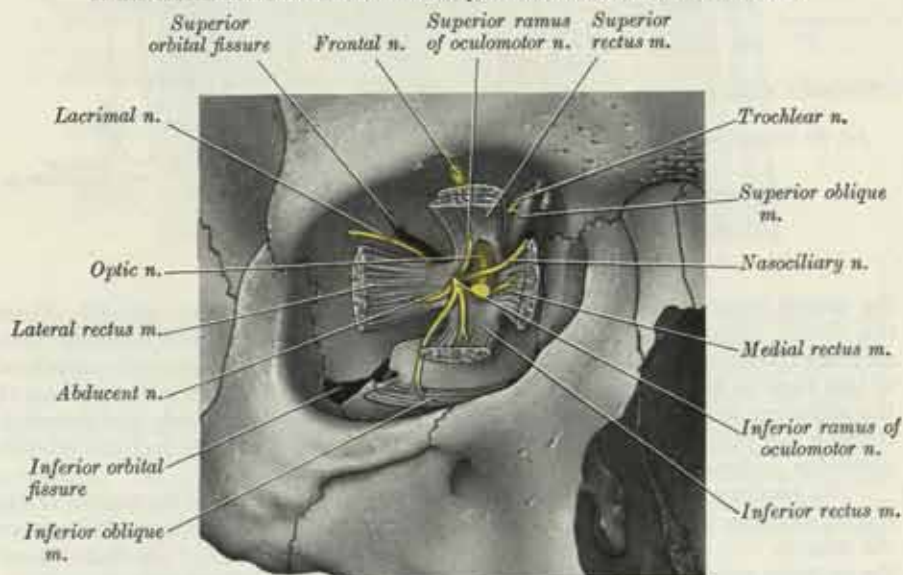


The ophthalmic veins often pass through the common tendinous ring.

the inferior cerebellar peduncle, the motor part being the more medial; the eighth nerve lies immediately to the lateral side of the sensory root.

The *motor root* supplies the muscles of the face, scalp, and auricle, the buccinator, platysma, stapedius, stylohyoid, and posterior belly of the digastric. The

FIG. 943.—A dissection of the right orbit viewed from in front, to show the origins of the orbital muscles and the relative positions of the nerves of the orbit.

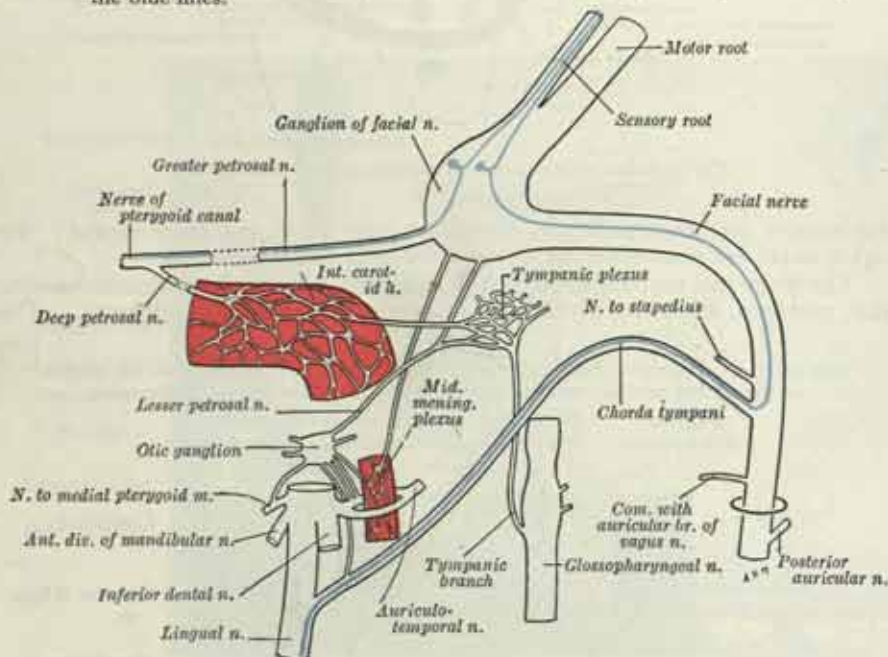


Note.—The levator palpebrae superioris m. is not labelled, but it is shown, cut, immediately above the superior rectus m.

sensory root conveys from the chorda tympani nerve the fibres of taste for the anterior two-thirds of the tongue, and from the palatine and greater petrosal nerves the fibres of taste from the soft palate; in addition, it is believed to transmit the preganglionic parasympathetic (secretomotor) fibres for the submandibular and sublingual salivary glands, for the lacrimal gland, and for the glands of the nasal and palatine mucosae.

The **nucleus** from which most of the motor fibres of the facial nerve are derived lies deeply in the reticular formation of the lower part of the pons. It is situated behind the dorsal nucleus of the corpus trapezoidum (fig. 837) and ventrimedial to the nucleus of the spinal tract of the trigeminal nerve. It represents the branchial (special visceral) efferent column, but it lies much more deeply in the pons than might be expected, and its outgoing fibres pursue a very unusual course. Both these features are explicable in accordance with the principle of neurobiotaxis (p. 966). The nucleus receives fibres from the pyramidal tract of the opposite side. In addition, some of the efferent fibres of the facial nerve take origin from the *superior salivary nucleus*, which lies in the reticular formation, dorsilateral to the caudal end of the motor nucleus. It represents the general visceral efferent column, and it sends its fibres to join the sensory root, by which they are ultimately distributed through

FIG. 944.—A plan of the intrapetrous portion of the facial nerve, its branches and communications. The course of the taste fibres from the mucous membrane of the palate and from the anterior two-thirds of the tongue is represented by the blue lines.



the chorda tympani to the submandibular and sublingual salivary gland.* From this double origin the fibres of the *motor root* pass backwards and medially, and, reaching the lower end of the nucleus of the abducent nerve, run upwards superficial to this nucleus beneath the colliculus facialis. At the upper end of the nucleus of the abducent nerve they make a second bend, and run downwards and forwards through the pons to their point of emergence between the olive and the inferior cerebellar peduncle (figs. 824, 837).

The **sensory nucleus** of the facial nerve is the upper part of the *nucleus of the tractus solitarius* of the medulla oblongata (p. 954). It receives afferent fibres from the sensory root and sends efferent fibres to the lateral nucleus of the thalamus of the opposite side. As they ascend through the midbrain and subthalamus regions, these fibres are closely related to the median plane (Wilfred Harris, *B.M.J.* i. 1952). From the thalamus they are relayed to the inferior part of the postcentral gyrus.

The *sensory root* consists of the central branches of the axons of the unipolar cells of the facial ganglion, which leave the trunk of the facial nerve in the internal acoustic meatus and pass centrally, in close relation with the motor root and the acoustic nerve, to enter the brain-stem at the lower border of the pons. The peripheral branches from the axons of the ganglion cells are the taste fibres contained

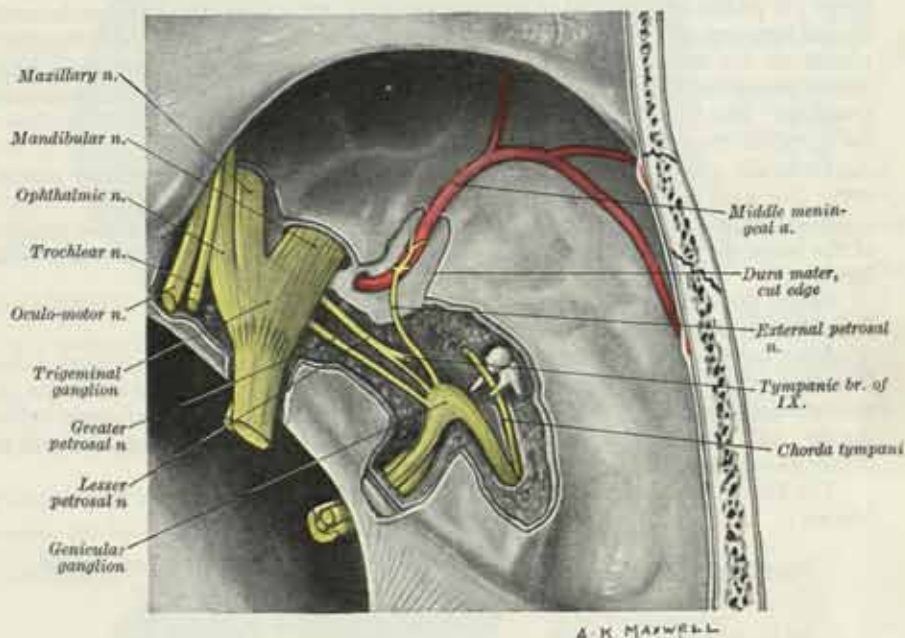
* The position of the nucleus of origin of the secretomotor fibres to the lacrimal gland is uncertain.

in the chorda tympani and the greater petrosal nerves. As already stated, it contains the efferent preganglionic parasympathetic fibres for the submandibular and sublingual salivary glands, the lacrimal gland, and paryngeal, nasal and palatine glands.

From their attachments to the brain, the two roots of the facial nerve pass laterally and forwards with the eighth nerve to the opening of the internal acoustic meatus. In the meatus the motor root lies in a groove on the upper and anterior surface of the acoustic nerve, the sensory root being placed between them.

At the bottom of the meatus, the facial nerve enters the facial canal. In this canal the nerve runs at first laterally above the vestibule, and reaching the medial wall of the epitympanic recess, bends sharply backwards above the promontory, and arches downwards in the medial wall of the aditus to the tympanic antrum. Finally it descends to reach the stylomastoid foramen. The point where it bends sharply backwards is named the *geniculum*; it presents a reddish gangliiform swelling

FIG. 945.—A dissection of the right middle cranial fossa, showing the course and some of the connexions of the facial nerve as it runs through the temporal bone.



named the *genicular ganglion* (fig. 944). On emerging from the stylomastoid foramen, the facial nerve runs forwards in the substance of the parotid gland (p. 1352), crosses the styloid process, the posterior facial vein and the external carotid artery, and divides behind the ramus of the mandible into branches which pierce the antero-medial surface of the parotid gland and diverge from one another under cover of it. They form a network (*parotid plexus*) and are distributed to the muscles of facial expression. As it emerges from the stylomastoid foramen, the facial nerve lies about 2 cm. deep to the middle of the anterior border of the mastoid process. Its course through the parotid gland can be represented by a short horizontal line drawn across the upper part of the lobule of the auricle (fig. 687).

The *branches of communication* of the facial nerve may be arranged as follows :

- | | |
|---|---|
| In the internal acoustic meatus | With the acoustic nerve. |
| At the facial ganglion | With the pterygopalatine ganglion by the greater petrosal nerve. |
| | With the otic ganglion by a branch which joins the lesser petrosal nerve. |
| | With the sympathetic plexus on the middle meningeal artery. |

In the facial canal	With the auricular branch of the vagus nerve.
At its exit from the stylo- mastoid foramen	{ With the glossopharyngeal, vagus, great auricular, and auriculotemporal nerves.
Behind the ear	With the lesser occipital nerve.
On the face	With the trigeminal nerve.
In the neck	With the transverse cutaneous cervical nerve.

In the internal acoustic meatus some minute filaments connect the facial nerve with the eighth nerve.

The *greater petrosal nerve* arises from the ganglion of the facial nerve, and consists chiefly of taste fibres which are distributed to the mucous membrane of the palate; but it also contains preganglionic parasympathetic fibres which are destined for the pterygopalatine ganglion and are there relayed through the zygomatic and lacrimal nerves (p. 1106) to the lacrimal gland and, through the nasal and palatine nerves to the glands of the nasal and palatine mucosæ (fig. 948). It receives a twig from the tympanic plexus, passes forwards through the hiatus on the anterior surface of the petrous portion of the temporal bone and runs in a groove on the bone. It passes beneath the trigeminal ganglion and reaches the foramen lacerum. In this foramen it is joined by the *deep petrosal nerve* (fig. 944) from the sympathetic plexus on the internal carotid artery, and forms the *nerve of the pterygoid canal*, which passes forwards through the pterygoid canal and ends in the pterygopalatine ganglion. The taste fibres pass without interruption through or over the surface of the ganglion into the palatine branches which spring from it.

From the ganglion of the facial nerve a branch runs to join the lesser petrosal nerve (fig. 944), and is conveyed through this nerve to the otic ganglion.

The sympathetic plexus on the middle meningeal artery is joined to the ganglion of the facial nerve by an inconstant branch, sometimes named the *external petrosal nerve*.

Before the facial nerve emerges from the stylomastoid foramen, it receives a twig from the auricular branch of the vagus.

After its exit from the stylomastoid foramen, the facial nerve receives a twig from the glossopharyngeal nerve, and communicates with the great auricular and auriculotemporal nerves in the parotid gland, with the lesser occipital nerve behind the ear, with the terminal branches of the trigeminal nerve on the face, and with the transverse cutaneous cervical nerve in the neck.

The *branches of distribution* (figs. 944, 946) of the facial nerve may be grouped as follows:

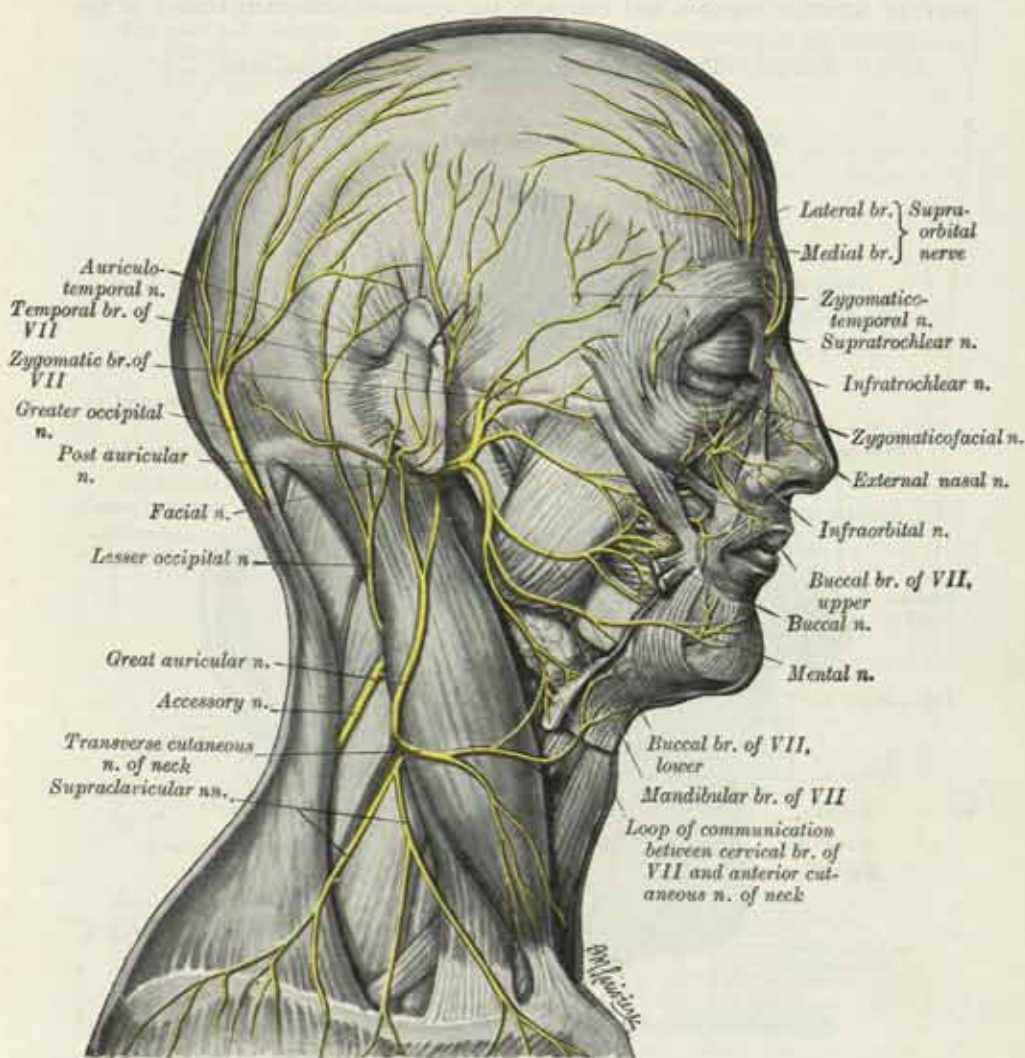
Within the facial canal	{ Nerve to the stapedius muscle. Chorda tympani.
At its exit from the stylo- mastoid foramen	{ Posterior auricular. Digastric, posterior belly. Stylohyoid.
On the face	{ Temporal. Zygomatic. Buccal. Mandibular. Cervical.

The *nerve to the stapedius* arises from the facial nerve opposite the pyramidal eminence on the posterior wall of the tympanic cavity; it passes forwards through a small canal to reach the muscle.

The *chorda tympani nerve* (figs. 939, 946) arises from the facial nerve about 6 mm. above the stylomastoid foramen. It runs upwards and forwards in a canal, and perforates the posterior bony wall of the tympanic cavity through the posterior canaliculus for the chorda tympani nerve, which is situated close to the posterior border of the medial surface of the tympanic membrane and on a level with the upper end of the manubrium of the malleus. It then passes forwards between the fibrous and mucous layers of the tympanic membrane, crosses the manubrium of the malleus, and re-enters the bone through the anterior canaliculus for the chorda tympani nerve, which is placed at the inner end of the petrotympanic fissure. The nerve now runs downwards and forwards on the medial surface of the spine of the

sphenoid bone (which it sometimes grooves) and passes deep to the lateral pterygoid muscle. In this part of its course the nerve lies lateral to the tensor veli palatini and is crossed by the middle meningeal artery, the roots of the auriculotemporal nerve and the inferior alveolar nerve. Finally it joins the posterior border of the lingual nerve at an acute angle. It contains efferent preganglionic parasympathetic (secretomotor) fibres which enter the submandibular ganglion, and are there relayed as postganglionic fibres to the submandibular and sublingual glands; the majority

FIG. 946.—The nerves of the right side of the scalp, face and neck.



of its fibres are afferent, and are continued onwards through the muscular substance of the tongue to the mucous membrane covering its anterior two-thirds, excluding the vallate papillæ; they constitute the nerve of taste for this portion of the tongue. Before uniting with the lingual nerve the chorda tympani is joined by a small branch from the otic ganglion.

The **posterior auricular nerve** arises close to the stylomastoid foramen and runs upwards in front of the mastoid process; here it is joined by a filament from the auricular branch of the vagus nerve, and communicates with the posterior branch of the great auricular nerve, and with the lesser occipital nerve. As it ascends between the external acoustic meatus and the mastoid process it divides into an auricular and an occipital branch. The *auricular branch* supplies the auricularis posterior and the intrinsic muscles on the cranial surface of the auricle. The

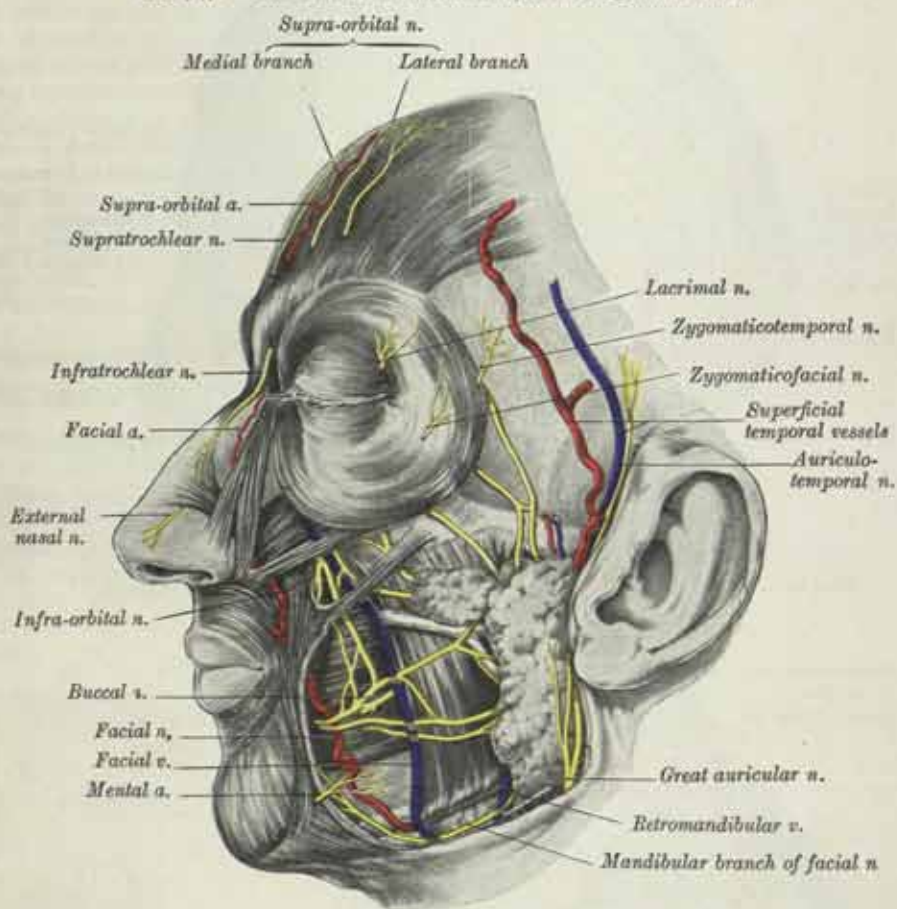
occipital branch, the larger, passes backwards along the superior nuchal line of the occipital bone, and supplies the occipital belly of the occipitofrontalis.

The **digastric branch** arises close to the stylomastoid foramen, and divides into several filaments which supply the posterior belly of the digastric; one of these filaments joins the glossopharyngeal nerve.

The **stylohyoid branch**, long and slender, frequently arises in conjunction with the digastric branch; it enters the middle part of the stylohyoid muscle.

The **temporal branches** cross the zygomatic arch to the temporal region. They supply the intrinsic muscles on the lateral surface of the auricle, the anterior and superior auricular muscles, and join with the zygomaticotemporal branch of the

FIG. 947.—The cutaneous branches of the left trigeminal nerve.



The branches of the left facial nerve are seen emerging from the parotid gland.

maxillary nerve, and with the auriculotemporal branch of the mandibular nerve. The more anterior branches supply the frontal belly of the occipitofrontalis, the orbicularis oculi and the corrugator, and join the supra-orbital and lacrimal branches of the ophthalmic nerve.

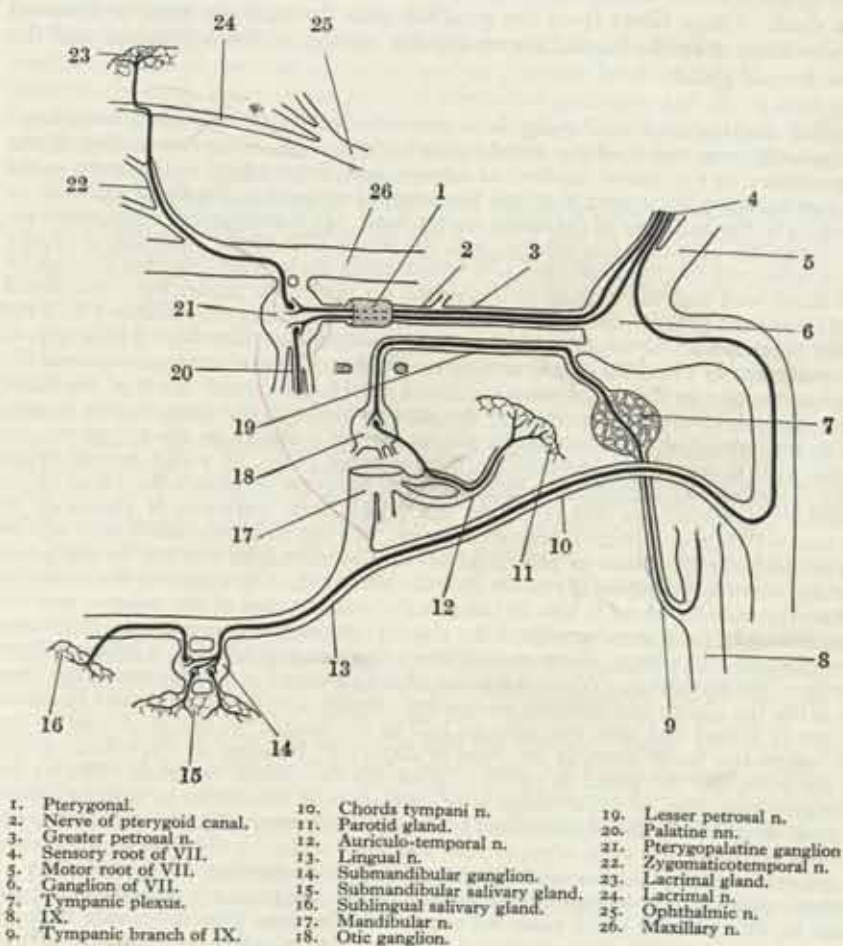
The **zygomatic branches** run across the zygomatic bone to the lateral angle of the eye; they supply the orbicularis oculi, and join with filaments of the lacrimal nerve and the zygomaticofacial branch of the maxillary nerve.

The **buccal branches** pass horizontally forwards to be distributed below the orbit and around the mouth. The *superficial branches* run between the skin of the face and the superficial muscles, and supply the latter; some are distributed to the procerus, joining with the infratrochlear and external nasal nerves. The upper *deep branches* pass under cover of the zygomaticus major and the levator labii superioris, supplying them and forming an *infra-orbital plexus* with the superior labial branches

of the infra-orbital nerve; they also supply the levator anguli oris, the zygomaticus minor, the levator labii superioris alæque nasi and the small muscles of the nose. These branches are sometimes described as lower zygomatic branches. The lower deep branches supply the buccinator and orbicularis oris, and join with filaments of the buccal branch of the mandibular nerve.

The **mandibular branch** runs forwards below the angle of the mandible under cover of the platysma. It lies at first superficial to the upper part of the digastric triangle and then turns upwards and forwards across the body of the mandible to lie

FIG. 948.—A diagram to show the parasympathetic connexions of the pterygo-palatine, otic and submandibular ganglia. The parasympathetic fibres, both pre- and postganglionic, are shown in heavy black lines.



Note.—The parasympathetic fibres in the palatine nerves (20) are secretomotor to the nasal, palatine and pharyngeal glands.

under cover of the depressor anguli oris (fig. 947). It supplies the risorius and the muscles of the lower lip and chin, and joins the mental nerve (p. 1112).

The **cervical branch** issues from the lower part of the parotid gland, runs forwards and downwards under cover of the platysma to the front of the neck. It supplies the platysma and communicates with the transverse cutaneous cervical nerve.

The **submandibular ganglion** is a small, somewhat fusiform ganglion which lies on the upper part of the hyoglossus muscle. Like the ciliary, pterygopalatine and otic ganglia it is a peripheral ganglion of the parasympathetic system. It is placed above the deep part of the submandibular gland and below the lingual nerve, from which it is suspended by an anterior and a posterior filament (fig. 935).

Although so intimately related to the lingual nerve, the ganglion is connected functionally with the facial nerve and its chorda tympani branch.

The *motor* or *parasympathetic root* is formed by the posterior filament connecting the ganglion to the lingual nerve. It conveys preganglionic fibres which arise in the superior salivary nucleus and run in the facial, chorda tympani and lingual nerves to reach the ganglion. There the fibres establish synaptic relations with the cells of the ganglion and the postganglionic fibres are secretomotor to the submandibular and the sublingual salivary glands. The *sympathetic root* is derived from the plexus on the facial artery. It consists of postganglionic fibres which take origin in the superior cervical ganglion and *pass through the submandibular ganglion without being interrupted*. They are vasomotor to the blood-vessels of the submandibular and sublingual glands.

Five or six *branches* arise from the ganglion and supply the submandibular gland and its duct. Other fibres from the ganglion pass through the anterior filament which connects it to the lingual nerve and are carried to the sublingual and the anterior lingual glands.

Applied Anatomy.—Facial palsy is commonly unilateral, and may be either: (1) *peripheral*, from lesion of the facial nerve; (2) *nuclear*, from destruction of the facial nucleus; or (3) *central, cerebral or supranuclear*, from injury in the brain to the fibres passing from the cortex through the internal capsule to the facial nucleus, or from injury to the face-area of the motor cortex itself. In supranuclear facial paralysis, which is usually part of a hemiplegia, it is the lower part of the face that is chiefly affected, while the forehead can be freely wrinkled on the palsied side, the eye can be closed fairly well and the eyeball is not rolled up under the upper lid; emotional movements of the face are executed much better than voluntary movements; and the electrical reactions of the muscles on the affected side are not altered. These apparently contradictory phenomena are usually ascribed to bilateral representation of the muscles concerned in the motor cortex. If the paralysis is due to lesion of the facial nucleus, the orbicularis oris escapes, as the nuclear origin of the nerve to this muscle seems to be connected with that of the tongue-nerves; otherwise the symptoms are identical with those of the common peripheral facial palsy, of which several types may be distinguished according to the point in its course at which the facial nerve is injured. If the lesion occurs (a) in the pons, facial paralysis is produced as in (d) below; taste and hearing are not affected, but the abducent nerve also will be paralysed because the fibres of the facial nerve loop round its nucleus in the pons. When the nerve is paralysed (b) in the petrous temporal, in addition to the paralysis of the motor nucleus, there is loss of taste in the anterior part of the tongue, and the patient is unable, from involvement of the chorda tympani, to recognise the difference between bitters and sweets, acids and salines: the sense of hearing is affected from paralysis of the stapedius. When the cause of the paralysis is (c) fracture of the base of the skull, the eighth and petrosal nerves are usually involved. It should be noted that taste is always lost over the anterior half of the tongue on the same side as the lesion, when the facial nerve is involved at any point between its superficial origin from the pons and the point at which it gives off the chorda tympani. But by far the commonest cause of facial palsy is (d) exposure of the nerve to cold or injury at or after its exit from the stylomastoid foramen (Bell's paralysis). In these cases the face looks asymmetrical even when at rest, and more so in the old than in the young. The affected side of the face and forehead remains motionless when voluntary or emotional movement is attempted. The lines on the forehead are smoothed out, the eye can be shut only by hand, tears fail to enter the lacrimal puncta because they are no longer in contact with the conjunctiva, the conjunctival reflex is absent and efforts, to close the eye merely cause the eyeball to roll upwards until the cornea lies under the upper lid. The tip of the nose is drawn over towards the sound side; the nasolabial fold is partially obliterated on the affected side, and the ala nasi does not move properly on respiration. The lips remain in contact on the paralysed side, but cannot be pursed for whistling; when a smile is attempted the angle of the mouth is drawn up on the unaffected side but on the affected side the lips remain nearly closed, and the mouth assumes a characteristic triangular form. During mastication food accumulates in the cheek, from paralysis of the buccinator, and dribbles or is pushed out from between the paralysed lips. On protrusion the tongue seems to be thrust over towards the palsied side, but verification of its position by reference to the incisor teeth will show that this is not really so. The platysma and the muscles of the auricle are paralysed; in severe cases the articulation of labials is impaired. The electrical reactions of the affected muscles are altered (reaction of degeneration), and the degree to which this alteration has taken place after a week or ten days gives a valuable guide to the prognosis. Most cases of Bell's palsy recover completely.

THE STATO-ACOUSTIC OR EIGHTH NERVE

The **stato-acoustic (auditory) nerve** appears in the groove between the pons and medulla oblongata, behind the facial nerve and in front of the inferior cerebellar peduncle (fig. 824). It consists of two sets of fibres, which, although differing in their principal central connexions, are both concerned in the transmission of afferent impulses from the internal ear to the brain. One set of fibres forms the vestibular nerve, or nerve of equilibration, and arises from the cells of the vestibular ganglion situated in the bottom of the internal acoustic meatus; the other set constitutes the cochlear nerve, or nerve of hearing, and takes origin from the cells of the spiral ganglion of the cochlea. Both ganglia are primitive in that they consist of bipolar nerve-cells; from each cell a central fibre passes to the brain, and a peripheral fibre to the internal ear.

Vestibular nerve (fig. 949 A).—The fibres of the vestibular nerve enter the brain medial to those of the cochlear nerve and on a higher level. They pass backwards through the pons between the inferior cerebellar peduncle and the spinal tract of the trigeminal nerve and divide into ascending and descending branches which mostly end in the vestibular nuclei, although many proceed direct to the cerebellum along the inferior cerebellar peduncle.

The **vestibular nucleus** of termination comprises the following subdivisions: (1) The **medial vestibular nucleus** (p. 960), which lies in the vestibular area of the floor of the fourth ventricle, crossed dorsally by the striæ medullares. It is the largest subdivision and extends upwards from the medulla oblongata into the pons. On transverse section it is triangular in outline. (2) The **inferior vestibular nucleus** (p. 960) lies lateral to the medial nucleus and reaches to a lower level in the medulla oblongata. It is placed between the medial nucleus and the inferior cerebellar peduncle, and the descending branches of the incoming vestibular fibres are closely applied to its lateral aspect. (3) The **lateral nucleus** (p. 963) lies ventrolateral to the upper part of the medial nucleus, and it is characterised by the large size of its constituent cells. Its upper end inclines dorsally and becomes continuous with the lower end of (4) the **superior nucleus**, which extends higher into the pons than the other subdivisions and occupies the upper part of the vestibular area.

Connexions.—Existing knowledge of the connexions of the whole vestibular system is far from complete. It is known that all the vestibular nuclei receive incoming fibres from the vestibular nerve and it is believed that they all receive *afferent cerebello-vestibular fibres* through the inferior cerebellar peduncle. These fibres are derived, for the most part, from the flocculus and nodule (posterior lobe), but others have been ascribed to the uvula, the lingula and the nucleus fastigii (fig. 949 A).

From the nuclei *efferent fibres* enter the inferior cerebellar peduncle, most of them being destined for the flocculus and the nodule, though some may pass to the uvula and the lingula, and some have been described as terminating in the nucleus fastigii. As already stated, many of the fibres of the vestibular nerve 'bypass' the nuclei and traverse the inferior cerebellar peduncle to reach the flocculus and the nodule.

As a whole, the vestibular nuclear complex acts as a relay station on an afferent cerebellar pathway, and is in turn a distributing station for efferent cerebellar fibres.

In addition, fibres from the vestibular nuclei enter the medial longitudinal bundle (fig. 857), in which they ascend, or descend, to reach the motor nuclei of the eye muscles and muscles of the neck. Further, from the large cells of the lateral vestibular nucleus, efferent fibres descend to form the vestibulo-spinal tract (p. 941) and fibres from the other nuclei are believed to join the lateral lemniscus and so may reach the inferior colliculus (corpus quadrigeminum) and the medial geniculate body and, eventually, the cerebral cortex, but cortical connexions, though long suspected, have never been demonstrated.

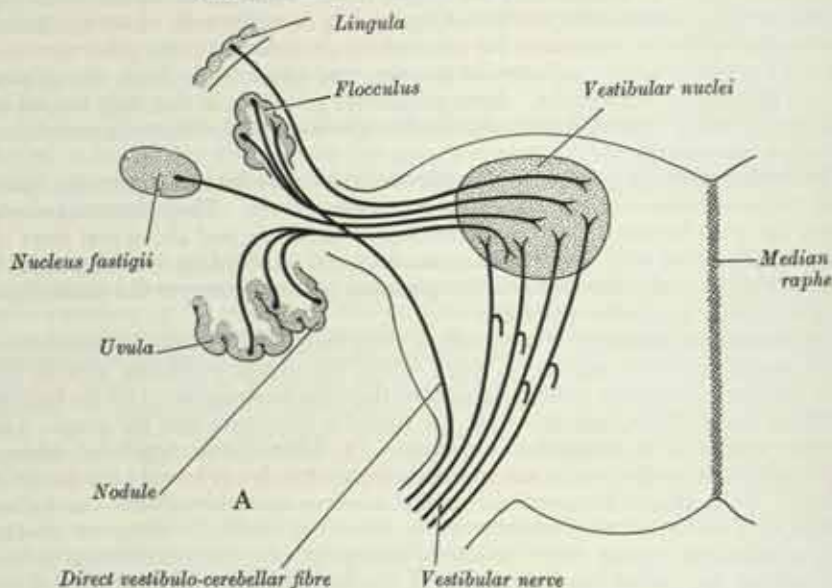
Speaking broadly, through its connexions the vestibular system is able to influence the movements of the eyes and head and the muscles of the trunk and limbs, so as to maintain equilibrium when loss of balance is threatened.

Cochlear nerve (fig. 949 B).—As it reaches the brain-stem the cochlear nerve is placed on the lateral side of the vestibular nerve, but the two nerves soon become separated by the inferior cerebellar peduncle. The cochlear nerve passes round the

lateral aspect of the peduncle, while the vestibular nerve penetrates the brain-stem on the medial side of that structure.

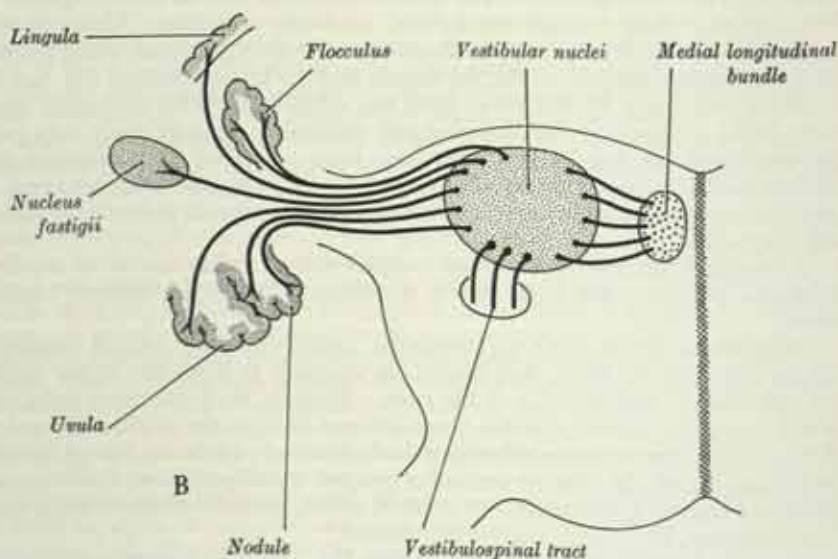
The **cochlear nuclei** are two in number. The *ventral cochlear nucleus* is placed on the ventrolateral aspect of the inferior cerebellar peduncle, and it receives the

FIG. 949 (A).—A diagram to show the afferent connexions of the group of nuclei in which the fibres of the vestibular nerve terminate.



Note.—In addition, one bundle of fibres is shown passing directly from the vestibular nerve through the inferior cerebellar peduncle to end in the flocculus (see text).

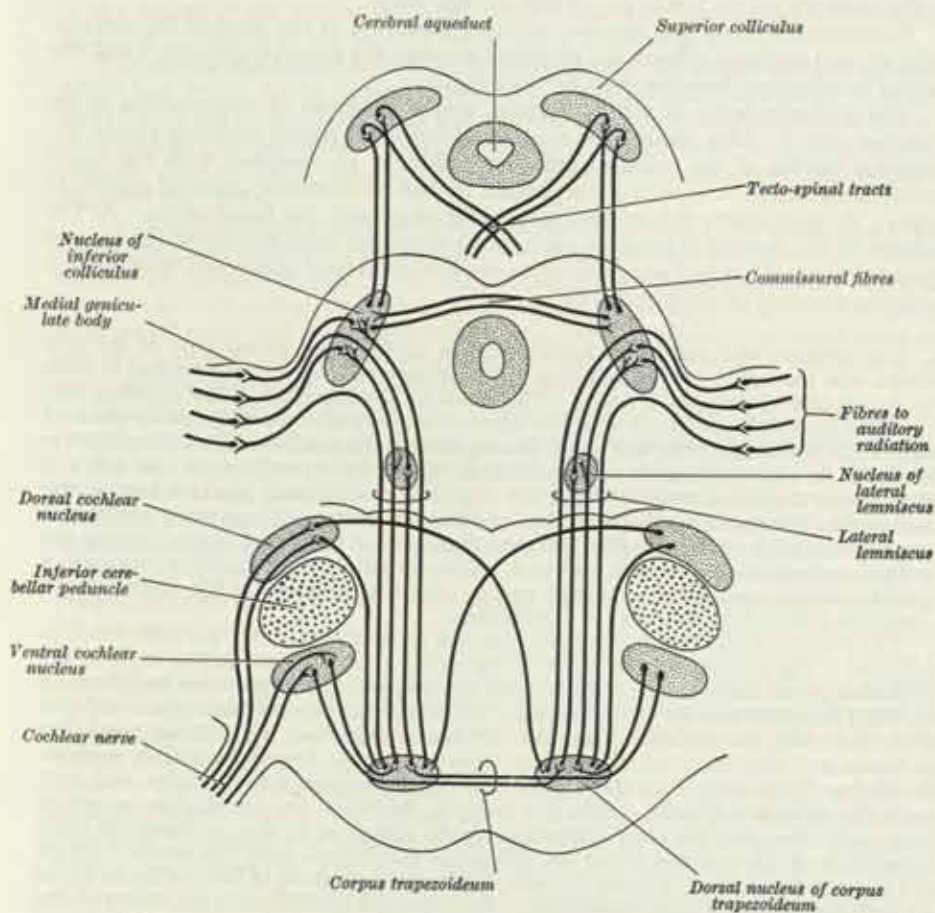
FIG. 949 (B).—A diagram to show the efferent connexions of the vestibular group of nuclei.



larger, ascending branches of the cochlear nerve. The *dorsal cochlear nucleus* lies on the dorsal aspect of the peduncle in the lateral part of the vestibular area of the floor of the fourth ventricle, where it forms the auditory tubercle. It receives the smaller, descending branches of the cochlear nerve.

It has been shown * that, the fibres of the cochlear nerve observe a spatial arrangement in their point of division. Those from the basal coil divide as soon as they enter the nucleus; those from the apical coil pass to the deepest part of the nucleus before dividing, while the remaining fibres maintain their appropriate positions in accordance with the particular part of the cochlea from which they have been derived. The afferent fibres to the ventral nucleus form synaptic connexions with only two or three of its cells, those to the dorsal nucleus end in a mass of fine terminals (neuropil) by means of which they can establish

FIG. 950.—A diagram to show the central connexions of the cochlear nerve and the auditory pathway through the brain stem.



Note.—Although, for technical reasons, they are shown in the figure as being of comparable size, the corpus trapezoideum constitutes a much more important and larger commissural bundle than the fibres connecting the nuclei of the two inferior colliculi.

connexions with a large number of its cells. This arrangement, considered in the light of the spatial representation of the cochlea in the audito-sensory cortex (p. 1047) suggests that the ventral nucleus and its neurones, with their presumably 'point to point' connexions, may be concerned with tonal values, while the dorsal nucleus is concerned with the transmission of sound, independent of its pitch or tone.

The *efferent fibres from the ventral cochlear nucleus* (second neurone fibres on the auditory pathway) end in the dorsal nucleus of the corpus trapezoideum, either of the same or of the opposite side. There they are relayed and the third neurone fibres turn upwards, forming an ascending tract, termed the *lateral lemniscus*. The second neurone fibres of the opposite side behave in the same way, and the inter-

* R. Lorente de Nò, *Laryngoscope*, 43, 1933.

sections of the contralateral fibres of the two sides form the *corpus trapezoideum** (fig. 950).

The efferent fibres from the dorsal cochlear nucleus establish similar connexions (fig. 950) and the third neurone fibres ascend in the lateral lemniscus, either of the same or of the opposite side.

Each lateral lemniscus, therefore, consists of third neurone fibres derived from both sides, and on its upward course to the mid-brain some of these have a cell-station in a small group of nerve-cells, intimately related to the tract and termed the *nucleus of the lateral lemniscus*. On reaching the mid-brain, some of the fibres end in the nucleus of the inferior colliculus, but others 'bypass' the nucleus and run in the inferior brachium to reach the medial geniculate body, where they are relayed to the auditory cortex (areas 41, 42 and 22, fig. 1047).

Commissural fibres link the two auditory pathways at the level of the inferior colliculi, and auditory reflexes are mediated through the superior colliculi † and the medial longitudinal bundles (figs. 857 and 950).

The auditory nerve is soft in texture, and is destitute of neurolemma in its proximal part.‡ After leaving the medulla oblongata it passes forwards across the posterior border of the middle cerebellar peduncle, in company with the facial nerve, from which it is partially separated by the labyrinthine (internal auditory) artery. It then enters the internal acoustic meatus with the facial nerve. At the bottom of the meatus it receives one or two filaments from the facial nerve, and splits into its *cochlear* and *vestibular* parts, the distribution of which will be described with the anatomy of the internal ear.

The cochlear and vestibular nuclei develop in the most dorsal part of the alar lamina, and the eighth nerve itself does not lie in series either with the ventral or with the dorsal cranial nerves (p. 1088). The mode of development of the cochlear and vestibular ganglia is consistent with this distinction, for their cells of origin are derived partly from the neural crest and partly from a dorsolateral ectodermal placode which is developed in association with the ectoderm of the auditory pit (p. 150). In fishes, a whole series of organs, termed lateral line organs or neuromasts, develops both in the head and in the trunk for the reception of vibration waves. These sense organs are very necessary for an aquatic life, but they disappear in terrestrial forms, leaving the auditory apparatus as their sole survivor. The acoustic nerve, therefore, occupies a special position amongst the cranial nerves, and the olfactory nerve alone can be compared with it with any sort of justification.

The vestibular and cochlear nerves, although apparently distinct, yet have much in common. The cochlear nerve, when it leaves the labyrinth and before it joins the vestibular nerve, carries with it fibres from the ampulla of the posterior semicircular duct and from the macula of the saccule. Winkler § has shown that some vestibular fibres run with the cochlear fibres on the lateral aspect of the inferior cerebellar peduncle and that some cochlear fibres terminate in the lateral vestibular nucleus. Vestibular fibres enter into the constitution of the corpus trapezoideum and may reach the inferior colliculus. The two systems, therefore, are not sharply separated from each other, and the chief distinction would appear to be that, whereas the main connexions of the cochlear nerve are ultimately established with the cerebral cortex and so enter the domain of consciousness, the main connexions of the vestibular nerve are with the spinal cord and cerebellum. Both systems can influence the motor nuclei of the brain-stem and the spinal medulla, and they appear to share the subsidiary nuclei (nuclei of corpus trapezoideum and nucleus of lateral lemniscus).

Applied Anatomy.—The eighth nerve is frequently injured, together with the facial nerve, in fracture of the middle fossa of the skull implicating the internal acoustic meatus. The nerve may be either torn across, producing permanent deafness, or bruised or pressed upon by extravasated blood or inflammatory exudation, when the deafness will in all probability be temporary. The nerve may also be injured by violent blows on the head without fracture of the skull, and deafness may arise from loud explosions, probably from some lesion of this nerve, which is more liable to be injured than the other cranial nerves on account of its structure. Tumours in the cerebello-pontine angle involve the eighth and facial nerves, as they lie in relation to the flocculus (fig. 824) at the lower border of the pons.

* H. W. Ades and J. M. Brookhart, *J. Neurophysiol.*, 13, 1950.

† H. W. Ades, *J. Neurophysiol.*, 7, 1944.

‡ H. Alan Skinner, *British Journal of Surgery*, Jan. 1929.

§ See first footnote, p. 965.

THE GLOSSOPHARYNGEAL NERVE (figs. 952, 953, 954)

The **glossopharyngeal nerve** contains motor and sensory fibres. It supplies motor fibres to the stylopharyngeus, secretomotor fibres to the parotid gland, and sensory fibres to the pharynx, the tonsil, and the posterior part of the tongue; it is also the nerve of taste for this part of the tongue. It is attached by three or four filaments to the upper part of the medulla oblongata, in the groove between the olive and the inferior cerebellar peduncle above the rootlets of the vagus nerve.

The **sensory nuclei** receive the central processes of the unipolar nerve-cells in the superior and inferior ganglia of the nerve; the fibres concerned with taste end in the *nucleus of the tractus solitarius* (p. 954) and those concerned with common sensation, probably in the sensory nuclei of the trigeminal nerve.*

The **motor nucleus** is formed by the upper part of the *nucleus ambiguus* (p. 957), which lies deeply in the formatio reticularis of the medulla oblongata. It is connected with the pyramidal tract of the opposite side, and sends its efferent fibres to the stylopharyngeus muscle. This nucleus represents the branchial (special visceral) efferent column, but it lies more deeply in the medulla oblongata than might be expected (fig. 831).

In addition, parasympathetic fibres join the motor part of the glossopharyngeal nerve from a representative of the general visceral efferent column which is termed the *inferior salivary nucleus*. This nucleus lies in the reticular formation below the superior salivary nucleus, and sends its fibres *via* the tympanic branch of the glossopharyngeal nerve and the tympanic plexus (p. 1279) to the lesser petrosal nerve and the otic ganglion, where they are relayed. The postganglionic fibres pass to the auriculo-temporal nerve and so reach the parotid gland (fig. 952).

From the medulla oblongata the glossopharyngeal nerve passes forwards and laterally towards the triangular depression into which the aquæductus cochleæ opens, on the inferior surface of the petrous portion of the temporal bone. It lies at first under cover of the flocculus, and rests on the jugular tubercle of the occipital bone, which is sometimes grooved by it. It leaves the skull by bending sharply downwards through the central part of the jugular foramen, anterior to the vagus and accessory nerves, and in a separate sheath of dura mater (fig. 951). In its transit through the jugular foramen it is lodged in a deep groove leading from the triangular depression for the aquæductus cochleæ, and here it is separated by the inferior petrosal sinus from the vagus and accessory nerves. The deep groove is converted into a canal by a bridge which is usually composed of fibrous tissue, but consists of bone in about 25 per cent. of skulls. After its exit from the skull it passes forwards between the internal jugular vein and internal carotid artery; it descends in front of the latter vessel, deep to the styloid process and the muscles connected with it, to reach the posterior border of the stylopharyngeus. It then curves forwards, lying upon the stylopharyngeus muscle, and either pierces the lower fibres of the superior constrictor of the pharynx or passes between the adjoining borders of the superior and middle constrictors (fig. 559) to be distributed to the tonsil, the mucous membrane of the pharynx and the posterior part of the tongue, and the mucous glands of the mouth.

Two ganglia, named the superior and the inferior, are situated on that portion of the nerve which traverses the jugular foramen (fig. 951).

The **superior ganglion** is situated in the upper part of the groove in which the nerve is lodged during its passage through the jugular foramen. It is very small, gives off no branches, and is usually regarded as a detached portion of the inferior ganglion.

The **inferior ganglion** is larger than the superior ganglion and is situated in a notch in the lower border of the petrous portion of the temporal bone (p. 324). Its cells are typical unipolar cells. Their peripheral branches convey taste and general sensibility from the mucous membrane of the posterior third of the tongue, including the sulcus terminalis and the vallate papillæ, and general visceral sensibility from the mucous membrane of the pharynx, soft palate and the fauces.

The glossopharyngeal nerve communicates with the sympathetic trunk, and with the vagus and facial nerves.

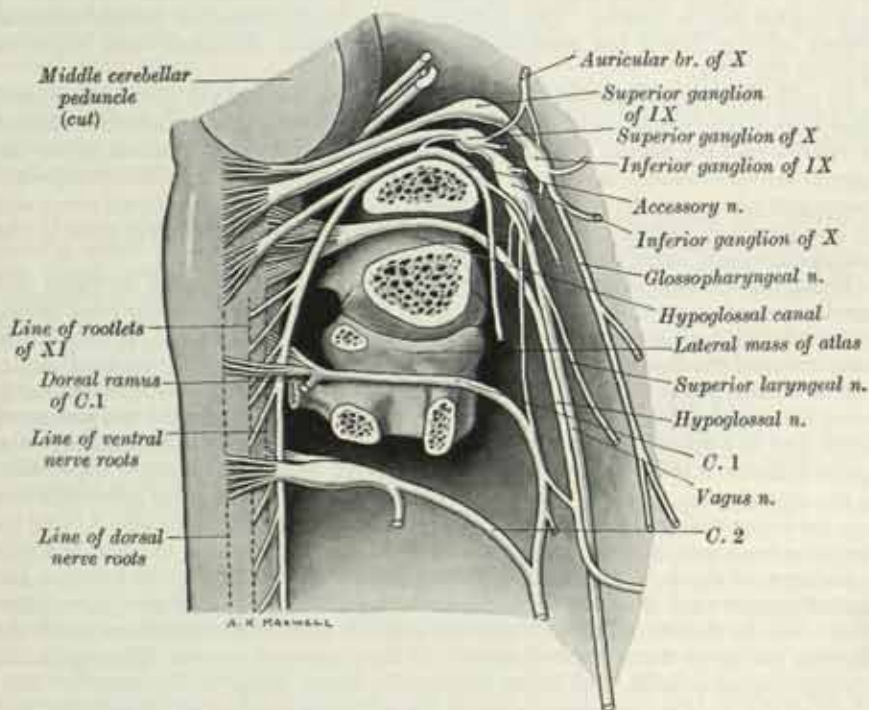
* A. Brodal, *Arch. Neurol. Psychiat.*, 57, 1947.

The inferior ganglion is connected by a filament with the superior cervical ganglion of the sympathetic. The branches to the vagus consist of two filaments which arise from the inferior ganglion; one joins the auricular branch, and the other the superior ganglion, of the vagus. The branch to the facial arises from the trunk of the glossopharyngeal nerve below the inferior ganglion; it perforates the posterior belly of the digastric muscle and joins the facial nerve near the stylo-mastoid foramen.

The *branches of distribution* of the glossopharyngeal nerve are: tympanic, carotid, pharyngeal, muscular, tonsillar and lingual.

The **tympanic nerve** arises from the inferior ganglion of the glossopharyngeal nerve, and ascends to the tympanic cavity through the inferior tympanic canaliculus (p. 324). In the tympanic cavity it divides into branches which form the *tympanic*

FIG. 951.—A diagram to show the communications between the last four cranial nerves of the right side.



The anterior condylar canal has been split in its long axis, and the transverse process of the atlas has been divided close to the lateral mass. The n. descendens hypoglossi is not shown.

plexus and are contained in grooves upon the surface of the promontory. This plexus gives off: (1) a branch to join the greater petrosal nerve (p. 1118); (2) branches to supply the mucous membrane lining the tympanic cavity, the auditory tube and the mastoid air-cells; and (3) the lesser petrosal nerve.

The *lesser petrosal nerve* contains the secretomotor fibres for the parotid gland (*vide infra*). It enters a small canal below the canal for the tensor tympani muscle, receives a connecting branch from the ganglion of the facial nerve and reaches the anterior surface of the temporal bone through a small opening on the lateral side of the hiatus for the greater petrosal nerve. It then passes through the foramen ovale or the canaliculus innominatus (p. 316) and joins the otic ganglion.

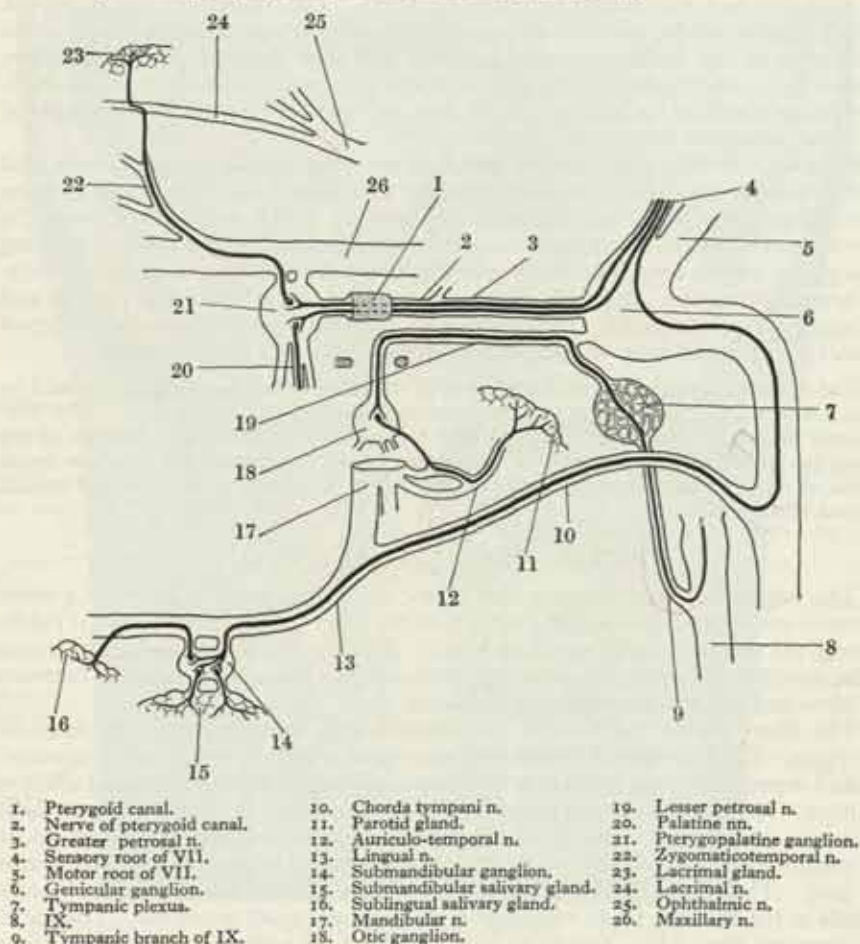
The **carotid artery**, often double, arises just below the skull, and descends on the internal carotid artery to be distributed to the wall of the carotid sinus and to the carotid body. It may communicate with the vagus (inferior ganglion or one of its branches) and with a branch from the sympathetic (superior cervical ganglion). Another branch, either from the preceding or from the main trunk, joins a fine plexus

which also supplies the carotid body. The other branches to this plexus spring from the sympathetic (superior cervical ganglion) and the vagus (p. 1133).

The **pharyngeal branches** are three or four filaments which unite, opposite the middle constrictor muscle of the pharynx, with the pharyngeal branch of the vagus nerve and the laryngopharyngeal branches of the sympathetic trunk to form the *pharyngeal plexus*; through this plexus the glossopharyngeal nerve supplies the mucous membrane of the pharynx with sensory branches.

The **muscular branch** supplies the stylopharyngeus muscle.

FIG. 952.—A diagram to show the parasympathetic connexions of the pterygo-palatine, otic and submandibular ganglia. The parasympathetic fibres, both pre- and postganglionic, are shown as heavy black lines.



- | | | |
|------------------------------|-----------------------------------|-------------------------------|
| 1. Pterygoid canal. | 10. Chorda tympani n. | 19. Lesser petrosal n. |
| 2. Nerve of pterygoid canal. | 11. Parotid gland. | 20. Palatine nn. |
| 3. Greater petrosal n. | 12. Auriculo-temporal n. | 21. Pterygopalatine ganglion. |
| 4. Sensory root of VII. | 13. Lingual n. | 22. Zygomaticotemporal n. |
| 5. Motor root of VII. | 14. Submandibular ganglion. | 23. Lacrimal gland. |
| 6. Genicular ganglion. | 15. Submandibular salivary gland. | 24. Lacrimal n. |
| 7. Tympanic plexus. | 16. Sublingual salivary gland. | 25. Ophthalmic n. |
| 8. IX. | 17. Mandibular n. | 26. Maxillary n. |
| 9. Tympanic branch of IX. | 18. Otic ganglion. | |

Note.—The parasympathetic fibres in the palatine nerves (20) are secretomotor to the nasal, palatine and pharyngeal glands.

The **tonsillar branches** supply the tonsil, and form around it a plexus with branches of the lesser palatine nerves; from this plexus filaments are distributed to the soft palate and the region of the fauces.

The **lingual branches** are two in number: one supplies the vallate papillae and the mucous membrane near the sulcus terminalis of the tongue (p. 1375); the other supplies the mucous membrane and follicular glands of the posterior one-third of the tongue, and communicates with the lingual nerve. It is the nerve of special sense (taste) and of general sensibility to the posterior one-third of the tongue.

The **otic ganglion** (figs. 939 and 944) is a small, oval-shaped, flattened ganglion of a reddish-grey colour, situated immediately below the foramen ovale. It is a peripheral ganglion of the parasympathetic system; topographically it is intimately

related to the mandibular nerve but, functionally, it is connected with the glossopharyngeal nerve.

It is in relation *laterally* with the trunk of the mandibular nerve at or near the point where it is joined by the motor root of the trigeminal, and it usually surrounds the origin of the nerve to the medial pterygoid muscle; *medially*, with the tensor veli palatini muscle, by which it is separated from the cartilaginous part of the auditory tube; *posteriorly*, with the middle meningeal artery.

The *motor* or *parasympathetic root* of the ganglion is formed by the lesser petrosal nerve, which conveys preganglionic fibres from the glossopharyngeal nerve. These fibres have their origin in the cells of the inferior salivary nucleus. They are relayed in the otic ganglion and the postganglionic fibres pass by a *communicating branch* to the auriculotemporal nerve. By it they are conveyed to the parotid gland (fig. 952), to which they supply secretomotor fibres. The *sympathetic root* is derived from the plexus on the middle meningeal artery. It contains post-ganglionic fibres which arise in the superior cervical ganglion and pass through the otic ganglion without being interrupted. Emerging with the parasympathetic fibres in the communicating branch to the auriculotemporal nerve, they are destined for the supply of the blood-vessels of the parotid gland.

Branches.—A twig connects the ganglion with the chorda tympani nerve and another ascends from it to join the nerve of the pterygoid canal. According to some neurologists these form an additional pathway by which taste fibres from the anterior two-thirds of the tongue may reach the facial ganglion without passing through the middle ear. The fibres concerned pass through the otic ganglion without being interrupted. Motor branches are supplied to the tensor veli palatini and the tensor tympani muscles. *They are derived from the nerve to the medial pterygoid muscle* (p. 1108) *and have no synaptic relations with the cells of the ganglion.*

The glossopharyngeal nerve is the nerve of the third branchial arch, or it would be more nearly correct to describe it as the post-trematic branch of that arch. The pre-trematic branch of the second (hyoid) arch is probably the tympanic branch of the glossopharyngeal nerve, but that is uncertain. Like the trigeminal and the facial nerves, the glossopharyngeal corresponds to a dorsal nerve which has acquired special visceral efferent fibres.

THE VAGUS NERVE (figs. 951, 953, 954)

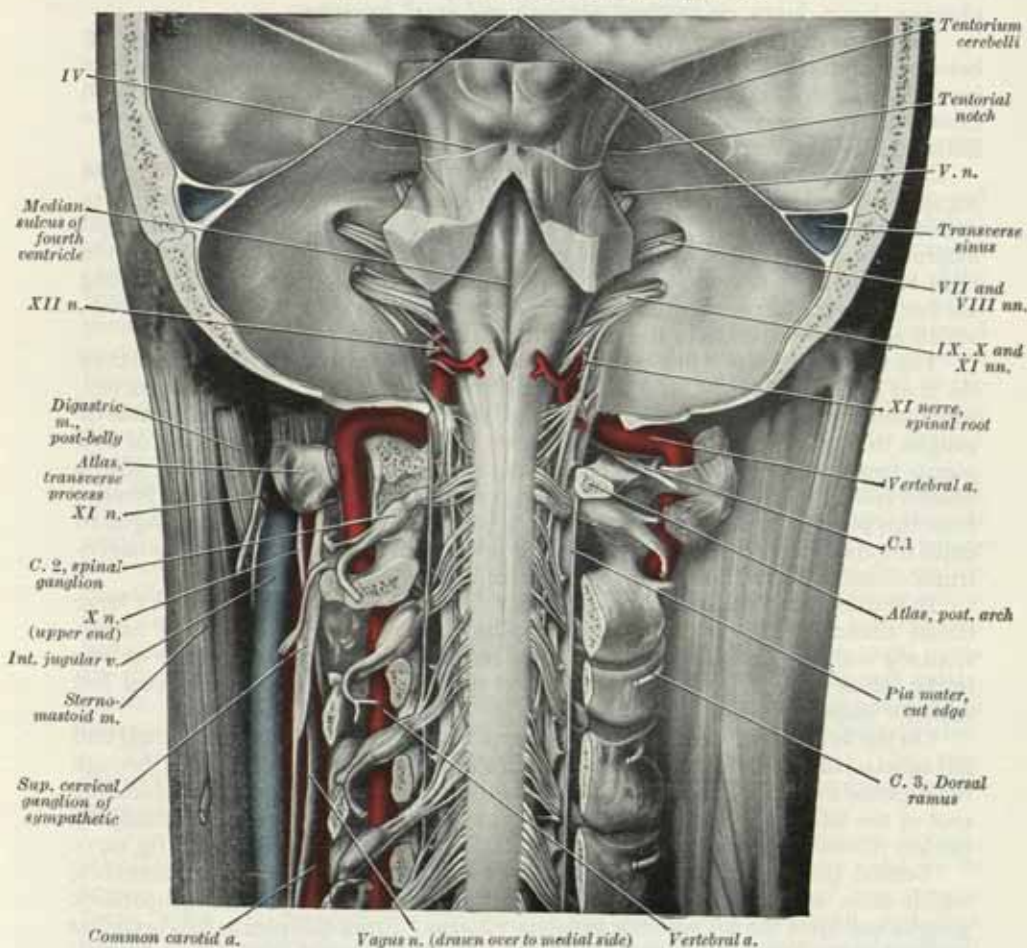
The **vagus nerve** is composed of motor and sensory fibres, and has a more extensive course and distribution than any of the other cranial nerves, since it passes through the neck and thorax to the abdomen. It is attached by eight or ten filaments to the medulla oblongata, below the glossopharyngeal nerve, in the groove between the olive and the inferior cerebellar peduncle.

The fibres of the vagus nerve are connected to three nuclei in the medulla oblongata. (1) The **dorsal nucleus** of the vagus is usually described as a mixed nucleus representing the fused general visceral efferent and general visceral afferent columns. It lies in the central grey matter of the lower, closed, part of the medulla oblongata, and extends upwards into the upper, open, part, where it is placed under the vagal triangle, separated from the hypoglossal nucleus by the nucleus intercalatus (p. 960). The *motor fibres* which arise from it are distributed to the involuntary muscle of the bronchi, heart, œsophagus, stomach and small intestines. The particular *sensory fibres* which terminate in the nucleus are uncertain. Although some authorities regard the nucleus of the tractus solitarius (p. 954) as predominantly a vagal nucleus, there is considerable evidence in favour of the view that afferent fibres from the œsophagus and the abdominal part of the alimentary canal terminate in the dorsal vagal nucleus (*see also* p. 954). (2) Below the origin of the fibres which join the glossopharyngeal nerve, the **nucleus ambiguus** (pp. 957 and 1127) gives origin to those fibres of the vagus nerve which are distributed to striped muscle, viz. the constrictor muscles of the pharynx and the intrinsic muscles of the larynx. It represents the branchial (special visceral) efferent column, and its position in the deeper part of the medulla oblongata is attributable to neurobiotaxis (p. 966). It is uncertain whether the muscles of the soft palate are innervated by the vagal part of the nucleus ambiguus or by the cranial nucleus of the accessory nerve. (3) The lower part of the **nucleus of the tractus solitarius** (pp. 954 and 957) receives those fibres of the vagus which are distributed through the internal laryngeal nerve to the taste-buds of the epiglottis and the valliculæ. The middle part of the nucleus

receives the visceral afferent fibres from the tongue, tonsil, palate and pharynx (IX). The upper part of the nucleus receives the taste fibres from the anterior two-thirds of the tongue and from the soft palate (VII).

The filaments of the nerve unite, and form a flat cord which passes below the flocculus of the cerebellum to the jugular foramen, through which it leaves the cranium. In emerging through this opening, the vagus nerve is accompanied by and contained in the same sheath of dura and arachnoid mater as the accessory nerve, a fibrous septum separating them from the glossopharyngeal nerve, which lies in

FIG. 953.—A dissection exposing the brain-stem and the upper part of the spinal medulla after removal of large portions of the occipital and parietal bones, and the cerebellum together with the roof of the fourth ventricle.



Note.—On the left side the foramina transversaria of the atlas and the third, fourth and fifth cervical vertebrae have been opened to expose the vertebral artery. On the right side the posterior arch of the atlas and the laminae of the succeeding cervical vertebrae have been divided and have been removed together with the vertebral spines and the laminae of the opposite side. The tentorium cerebelli and the transverse sinuses have been divided and their posterior portions removed.

front (fig. 951). In this situation the vagus nerve presents a well-marked enlargement, named the *superior ganglion*. After its exit from the jugular foramen the vagus nerve enlarges into a second swelling, named the *inferior ganglion*.

The *superior ganglion* is of a greyish colour, spherical in form, about 4 mm. in diameter. It is joined by one or two delicate filaments with the cranial root of the accessory nerve; it is connected by a twig with the inferior ganglion of the glossopharyngeal nerve, and with the sympathetic trunk by a filament from the superior cervical ganglion; the auricular branch of the ganglion gives off an ascending twig which joins the facial nerve (p. 1118).

The **inferior ganglion** is cylindrical in form, of a reddish colour, and 2.5 cm. long. It is connected with the hypoglossal nerve, the superior cervical ganglion of the sympathetic trunk, and the loop between the first and second cervical nerves. The cranial root of the accessory nerve passes over the ganglion, but is attached to it by fibrous tissue only.

Beyond the inferior ganglion the cranial root of the accessory nerve blends with the vagus nerve; its fibres are distributed principally to the pharyngeal and recurrent laryngeal branches of the vagus nerve.

The cells of both ganglia are unipolar, like the cells of a spinal ganglion. The superior ganglion is concerned with general somatic sensibility (auricular branch); the inferior ganglion is concerned with special visceral sensibility (taste, from the mucous membrane of the epiglottis) and general visceral sensibility from the larynx, pharynx, heart, lungs, œsophagus, stomach and small intestine.

The vagus nerve passes vertically down the neck within the carotid sheath, lying between the internal jugular vein and internal carotid artery as far as the upper border of the thyroid cartilage, and then between the same vein and the common carotid artery until it reaches the root of the neck. The further course of the nerve differs on the two sides of the body.

On the *right side* the vagus nerve continues downwards behind the internal jugular vein and crosses the first part of the subclavian artery. It enters the thorax and descends through the superior mediastinum, lying at first behind the right brachiocephalic vein, and then to the right of the trachea and posteromedial to the right brachiocephalic vein and the superior vena cava. The right pleura and lung are lateral to the nerve above, but are separated from it below by the azygos vein, which arches forward above the root of the right lung (fig. 767).

The nerve next passes behind the right bronchus to reach the posterior aspect of the root of the right lung, and there breaks up into posterior bronchial branches, which unite with filaments from the second, third and fourth thoracic sympathetic ganglia to form the *right posterior pulmonary plexus*. From the lower part of this plexus two or three branches descend on the back of the œsophagus, where, with a branch from the left vagus, they form the posterior part of the *œsophageal plexus*; from this plexus a trunk is re-formed which is continued behind the œsophagus to enter the abdomen through the œsophageal opening in the diaphragm. This nerve-trunk contains fibres from both vagus nerves.

In the abdomen the *posterior vagal trunk* divides into a small gastric and a large cœliac branch. The gastric branch supplies the postero-inferior surface of the stomach with the exception of the pyloric canal. The cœliac branch ends chiefly in the cœliac ganglia, but sends twigs to the splenic, hepatic, renal, suprarenal and superior mesenteric plexuses.

On the *left side* the vagus enters the thorax between the left common carotid and left subclavian arteries, and behind the left brachiocephalic vein. It descends through the superior mediastinum, crosses the left side of the aortic arch and passes behind the root of the left lung. Just above the aortic arch the nerve is crossed superficially by the left phrenic nerve, and on the arch by the left superior intercostal vein (fig. 997).

Behind the root of the left lung it divides into posterior bronchial branches, which unite with filaments of the second, third and fourth thoracic sympathetic ganglia and form the *left posterior pulmonary plexus*. From this plexus two branches descend on the front of the œsophagus where, with a twig from the right posterior pulmonary plexus, they form the anterior part of the *œsophageal plexus*; from this plexus a trunk, containing fibres from both vagus nerves, is continued in front of the œsophagus, and enters the abdomen through the œsophageal opening of the diaphragm.

In the abdomen the *anterior vagal trunk* supplies twigs to the cardiac antrum, and then divides into right and left groups of branches. The fibres of the left group follow the lesser curvature of the stomach and supply the anterosuperior surface of this viscus. The right group consists of three main branches. The first, which may be duplicated, runs between the layers of the lesser omentum towards the porta hepatis, and divides into (a) upper branches which enter the porta hepatis, and (b) lower branches which supply chiefly the pyloric canal, the pylorus, the superior and the descending parts of the duodenum, and the head of the pancreas. The second branch is distributed to the anterosuperior surface of the body of the stomach; the third branch follows the lesser curvature of the stomach as far as the incisura angularis.*

* E. D'Arcy M'Crea, *J. Anat.*, 59, 1924.

The *branches* of the vagus nerve are :

In the jugular fossa . . .	{ Meningeal. Auricular.
In the neck	{ Pharyngeal. Branches to carotid body. Superior laryngeal. Recurrent laryngeal (right). Cardiac.
In the thorax	{ Cardiac. Recurrent laryngeal (left). Pulmonary. Esophageal.
In the abdomen	{ Gastric. Cœliac. Hepatic.

The **meningeal branch** springs from the superior ganglion of the vagus nerve and is distributed to the dura mater in the posterior fossa of the skull.

The **auricular branch** arises from the superior ganglion of the vagus nerve, and is joined soon after its origin by a filament from the inferior ganglion of the glosso-pharyngeal; it passes behind the internal jugular vein, and enters the mastoid canaliculus on the lateral wall of the jugular fossa. Traversing the substance of the temporal bone, it crosses the canal for the facial nerve about 4 mm. above the stylo-mastoid foramen, and here it gives off an ascending branch which joins the facial nerve. It then passes through the tympanomastoid fissure, and divides into two branches; one joins the posterior auricular nerve, the other is distributed to the skin of part of the cranial surface of the auricle and to the posterior wall and the floor of the external acoustic meatus and to the adjoining part of the outer surface of the tympanic membrane.

The **pharyngeal branch**, which is the principal motor nerve of the pharynx, arises from the upper part of the inferior ganglion of the vagus nerve, and consists principally of filaments from the cranial root of the accessory nerve. It passes between the external and internal carotid arteries to the upper border of the middle constrictor muscle of the pharynx, where it divides into numerous filaments which join with branches from the sympathetic trunk, the glossopharyngeal and external laryngeal nerves, to form the *pharyngeal plexus*. Through this plexus vagal fibres are distributed to the muscles of the pharynx, and the muscles of the soft palate, except the tensor veli palatini. A minute filament joins the hypoglossal nerve as the latter winds round the occipital artery, and is often termed the *ramus lingualis vagi*.

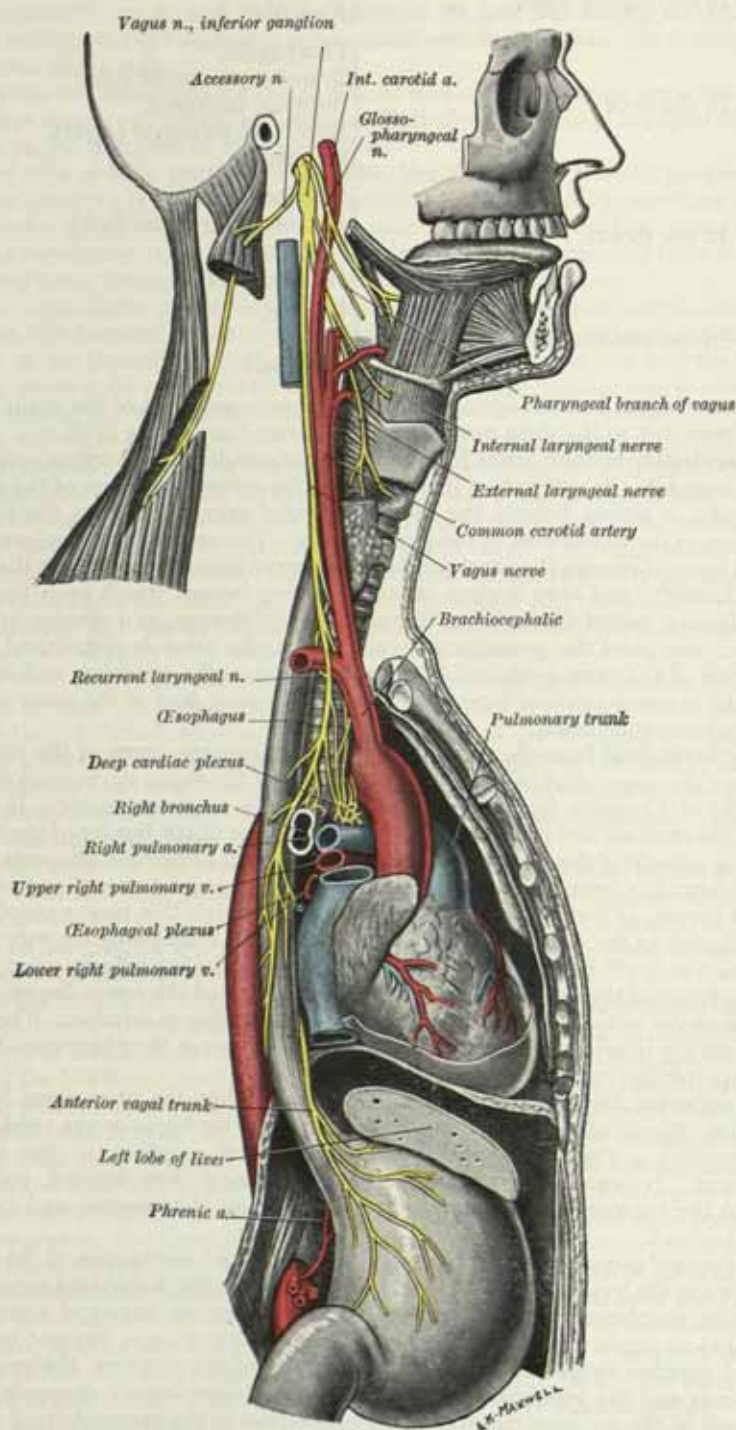
The *branches to the carotid body* are minute and variable in number. They may spring from the inferior ganglion or they may travel either in the pharyngeal branch or the superior laryngeal nerve.

The **superior laryngeal nerve**, which is larger than the pharyngeal branch, arises from the middle of the inferior ganglion of the vagus nerve, and in its course receives a branch from the superior cervical ganglion of the sympathetic trunk. It descends, by the side of the pharynx, first behind, and then medial to the internal carotid artery, and divides into the internal and external laryngeal nerves.

The **internal laryngeal nerve** is sensory to the mucous membrane of the larynx as far down as the level of the vocal folds. It descends to the thyrohyoid membrane, pierces this membrane at a higher level than the superior laryngeal artery, and divides into an upper and a lower branch. The upper branch is directed horizontally, and supplies twigs to the mucous membrane of the pharynx, the epiglottis, the vallecule and the vestibule of the larynx. The lower branch descends in the medial wall of the piriform recess, and gives branches to the aryepiglottic fold, and to the mucous membrane on the back of the arytenoid cartilage. It also supplies one or two branches to the arytenoideus muscle, and these branches unite with twigs from the recurrent laryngeal nerve to the same muscle. The internal laryngeal nerve ends by piercing the inferior constrictor muscle of the pharynx, and joining with an ascending branch from the recurrent laryngeal nerve.*

* T. F. M. Dilworth, *J. Anat.*, 56, 1921.

FIG. 954.—The course and distribution of the glossopharyngeal, vagus and accessory nerves. Diagrammatic.



The *external laryngeal nerve*, which is the smaller of the two, descends under cover of the sternothyroid muscle in company with the superior thyroid artery but on a deeper plane; it lies at first on the inferior constrictor muscle of the pharynx, and then, piercing that muscle, winds closely round the inferior thyroid tubercle and reaches the cricothyroid muscle, which it supplies. It gives branches also to the

pharyngeal plexus and to the inferior constrictor; behind the common carotid artery it communicates with the superior cardiac nerve.

The **recurrent laryngeal nerve** differs, as to its origin and course, on the two sides of the body. On the *right* side it arises from the vagus nerve in front of the first part of the subclavian artery; it winds from before backwards round that vessel, and ascends obliquely to the side of the trachea behind the common carotid artery. Near the lower pole of the lobe of the thyroid gland the nerve is always intimately related to the inferior thyroid artery; it may cross either in front of or behind the vessel, or may pass between its branches. On the *left* side, it arises from the vagus nerve on the left of the arch of the aorta, and winds below the arch immediately behind the attachment of the ligamentum arteriosum to the concavity of the arch, and then ascends to the side of the trachea. The nerve on each side ascends in or near the groove between the trachea and œsophagus, and is intimately related to the medial surface of the thyroid gland before it passes under the lower border of the inferior constrictor muscle and enters the larynx behind the articulation of the inferior cornu of the thyroid with the cricoid cartilage. It gives branches to all the muscles of the larynx, excepting the cricothyroid; it communicates with the internal laryngeal nerve, and supplies sensory filaments to the mucous membrane of the larynx below the level of the vocal folds.

As the recurrent laryngeal nerve hooks round the subclavian artery, or the arch of the aorta, it gives several cardiac filaments to the deep part of the cardiac plexus. As it ascends in the neck it gives branches, more numerous on the left than on the right side, to the mucous membrane and muscular coat of the œsophagus; branches to the mucous membrane and muscular fibres of the trachea; and some filaments to the inferior constrictor muscle.

The **cardiac branches**, two or three in number, arise from the vagus nerve at the upper and lower parts of the neck. The *upper branches* are small, and join with the cardiac branches of the sympathetic trunk. They can be traced to the deep part of the cardiac plexus.

The *lower branches* arise at the root of the neck. That from the right vagus passes in front of or by the side of the brachiocephalic artery, and proceeds to the deep part of the cardiac plexus; that from the left runs down across the arch of the aorta, and joins the superficial part of the cardiac plexus.

Additional cardiac branches arise from the trunk of the right vagus nerve as it lies by the side of the trachea, and from both recurrent laryngeal nerves. They end in the deep part of the cardiac plexus. The cardiac plexus is described on p. 1214.

The **anterior pulmonary branches**, two or three in number and of small size, are distributed on the anterior surface of the root of the lung. They join with filaments from the sympathetic, and form the *anterior pulmonary plexus*.

The **posterior pulmonary branches**, more numerous and larger than the anterior, are distributed on the posterior surface of the root of the lung; they are joined by filaments from the third and fourth (sometimes also from the first and second) thoracic ganglia of the sympathetic trunk, and form the *posterior pulmonary plexus*. Branches from this plexus accompany the ramifications of the bronchi and supply their constrictor muscles.

The **œsophageal branches** are given off both above and below the pulmonary branches; the lower are more numerous and larger than the upper. They form, as already described (p. 1132), the *œsophageal plexus*. From this plexus filaments are distributed to the œsophagus and to the back of the pericardium.

The **gastric branches** are distributed to the stomach, the anterosuperior surface of which is mainly supplied by the left vagus, and the postero-inferior surface mainly by the right. The gastric branches sometimes form *anterior* and *posterior gastric plexuses*. "The pyloric canal, sphincter, and first stage of the duodenum receive their nerve-supply from above, receiving twigs from the vagal branches to the liver" (M'Crea).

The **cœliac branches** are derived from the right vagus: they join the cœliac ganglia.

The **hepatic branches** arise from both vagus nerves (p. 1132): they join the hepatic plexus and through it are conveyed to the liver.

The **renal branches** arise from both vagus nerves and join the renal plexus (p. 1217).

The vagus is a composite nerve and has been formed by the fusion of a number of dorsal nerves. It innervates the fourth, fifth and sixth branchial arches, but, in view of the presence of the large intestinal ramus in the vagus nerves of all fishes, it is impossible to speak with confidence as to the original number of its constituents.

It is interesting to observe that although the seventh and ninth cranial nerves have lost their somatic afferent component, it still persists in connexion with the tenth nerve, as its auricular branch. There are, however, some good grounds for supposing that its afferent fibres terminate in the nucleus of the spinal tract of the trigeminal nerve. However that may be, it is certain that irritation of the terminal twigs of the auricular branch in the external acoustic meatus is capable of producing an efferent vagal response.

Applied Anatomy.—The trunk of the vagus is rarely injured, but the functions of the nerve may be interfered with by damage to its nucleus of origin in the medulla; by thickening or growth from the meninges or bones, or aneurysm of the basilar artery, before its exit from the skull; injuries such as gunshot or punctured wounds in the neck or injuries during such operations as ligature of the carotid artery, removal of tuberculous glands or other deep-seated tumours. The vagus may also be compressed by aneurysms of the carotid artery, and its deep origin becomes affected in bulbar paralysis. The symptoms produced by paralysis of the nerve are palpitation, with increased frequency of the pulse, constant vomiting, slowing of the respiration, and a sensation of suffocation.

'Reflexes' in connexion with the branches of the vagus are not infrequent. The 'ear cough' is perhaps one of the commonest, where a plug of wax in the acoustic meatus may, by irritating the filaments of the auricular nerve, be responsible for a persistent cough. Syringing the external acoustic meatus frequently produces cough, and, in children, vomiting is not uncommon as the result of such a procedure; moreover, in people with weak hearts, syringing the ear has been responsible for a sudden fatal syncope, by reflex irritation of the cardiac branches. Another very common example is the persistent cough which is frequently due to enlarged bronchial glands in children, the irritation of which is referred to the superior laryngeal filaments.

The anatomy of the laryngeal nerves is of importance in considering some of the morbid conditions of the larynx. When the peripheral terminations of the superior laryngeal nerve are irritated by some foreign body passing over them reflex spasm of the glottis is the result. When its trunk is pressed upon by, for instance, a goitre or an aneurysm of the upper part of the carotid, there is a peculiar dry, brassy cough. When the nerve is paralysed, there is anæsthesia of the mucous membrane of the larynx, so that foreign bodies can readily enter the cavity, and, as the nerve also supplies the cricothyroid muscle, the vocal folds cannot be made tense, and the voice is deep and hoarse. Paralysis may be the result of bulbar paralysis; may be a sequel to diphtheria, when both nerves are usually involved; or it may, though less commonly, be caused by the pressure of tumours or aneurysms, when the paralysis is generally unilateral. Irritation of the recurrent laryngeal nerves produces spasm of the muscles of the larynx. When both recurrent laryngeal nerves are paralysed, the vocal folds are motionless, in the so-called 'cadaveric position'—that is to say, in the position in which they are found in ordinary tranquil respiration; neither closed as in phonation, nor widely open as in deep inspiratory efforts. When one recurrent laryngeal nerve is paralysed, the vocal fold of the same side is motionless, while the opposite one crosses the median plane to accommodate itself to the affected one; hence phonation is possible, but the voice is altered and weak in timbre. Paralysis of the adductor muscles of the larynx on both sides is quite common, and is usually functional in nature. The voice is reduced to a whisper, but the power of coughing is preserved.

THE ACCESSORY NERVE (figs. 951, 953, 954)

The **accessory nerve** is formed by the union of cranial and spinal roots. It represents the separated caudal rootlets of the vagus, but the separation is only partial, for its constituent parts are associated with each other only for a very short part of their course before the cranial part joins the vagus to be distributed through its branches. It is, however, both customary and convenient to describe it as a separate cranial nerve.

The **cranial root** is the smaller; its fibres arise from the cells of an elongated nucleus which is continuous above with the lower end of the **nucleus ambiguus** (p. 957). They emerge as four or five delicate rootlets from the side of the medulla oblongata, below the roots of the vagus. The nerve runs laterally to the jugular foramen, where it interchanges fibres with the spinal root or becomes united to it for a short distance; here it is also connected by one or two filaments with the

superior ganglion of the vagus. It passes through the jugular foramen, separates from the spinal portion, and is continued over the inferior ganglion of the vagus, to the surface of which it is adherent. It is distributed principally by the pharyngeal and recurrent laryngeal branches of the vagus. It is probably the source of the motor fibres which run in the former to supply the muscles of the soft palate, with the exception of the tensor veli palatini. Some filaments from it are continued into the trunk of the vagus below the ganglion, to be distributed with the recurrent laryngeal nerve and possibly also with the cardiac nerves.

The **spinal root** is firm in texture, and its fibres arise from an elongated nucleus of motor cells which is situated in the lateral part of the anterior grey column of the spinal medulla, and extends downwards as low as the level of the fifth cervical nerve. Passing through the lateral white column of the spinal medulla, they emerge on its surface midway between the ventral and dorsal nerve-roots of the upper cervical nerves (fig. 951), and unite to form a trunk, which ascends between the ligamentum denticulatum and the dorsal roots of the spinal nerves, and enters the skull through the foramen magnum, behind the vertebral artery (fig. 953). It is then directed upwards and laterally to the jugular foramen, through which it passes in the same sheath of dura mater as the vagus nerve, but separated from that nerve by a fold of the arachnoid mater. In the jugular foramen, it receives one or two filaments from the cranial root, or else joins it for a short distance and then parts from it again. At its exit from the jugular foramen, it runs laterally and backwards posterior to the internal jugular vein in about 66 per cent. of subjects, and anterior to it in about 33 per cent. (Tandler). In this situation the accessory nerve crosses the transverse process of the atlas and is itself crossed by the occipital artery. The nerve then descends obliquely, passing deep to the styloid process, the stylohyoid muscle and the posterior belly of the digastric. Accompanied by the upper sternomastoid branch of the occipital artery, it reaches the upper part of the sternomastoid and pierces its deep surface, supplying it and joining with branches from the second cervical nerve. Emerging above the middle of the posterior border of the sternomastoid, the nerve crosses the posterior triangle of the neck lying on the levator scapulae muscle (fig. 945), from which it is separated by the prevertebral layer of the deep cervical fascia and the fatty tissue which occupies the triangle. Here it is comparatively superficial, being related to the superficial cervical lymph nodes and receiving communications from the second and third cervical nerves. Finally, about 5 cm. above the clavicle, the accessory nerve disappears under the anterior border of the trapezius and, together with branches from the third and fourth cervical nerves, forms a plexus on the deep surface of the muscle. From this plexus the trapezius receives its innervation. The course of the accessory nerve in the neck can be represented by a line drawn downwards from the lower and anterior part of the tragus to the tip of the transverse process of the atlas, and then downwards and backwards, across the elevation produced by the sternomastoid muscle and the depression corresponding to the posterior triangle of the neck, to a point on the anterior border of the trapezius 5 cm. above the clavicle (fig. 765).

Applied Anatomy.—The functions of the accessory nerve may be interfered with by central changes; or at its exit from the skull, by fractures running across the jugular foramen; or in the neck, by inflamed lymph nodes, etc. The acute wry-neck in children is most commonly due to inflamed or suppurating lymph nodes, and rapidly subsides with appropriate treatment. Central irritation causes clonic spasm of the sternomastoid and trapezius muscles, or, as it is termed, spasmodic torticollis. In cases of this affection in which all previous palliative treatment has failed, and the spasms are so severe as to undermine the patient's health, division or excision of a portion of the accessory nerve has been resorted to.

In cases where extensive dissections are undertaken in the posterior triangle of the neck for the excision of tuberculous nodes, it is essential that this nerve should be sought at the outset and isolated from the mass of inflamed nodes so as to preserve its continuity.

THE HYPOGLOSSAL NERVE (figs. 955, 956)

The **hypoglossal nerve** is the motor nerve of the tongue. It is in series with the third, fourth and sixth cranial nerves and the ventral nerve-roots of the spinal nerves, and represents the fused ventral roots of, probably, four precervical or spino-occipital nerves, the dorsal roots of which have disappeared entirely.

The **nucleus** from which its fibres arise is in line with the base of the anterior grey column of the spinal cord. This nucleus is about 2 cm. long, and its upper part corresponds with the hypoglossal triangle of the floor of the fourth ventricle (p. 987). The lower part of the nucleus extends downwards into the closed part of the medulla oblongata, and there lies in the ventral part of the central grey matter, close to the median plane (fig. 829). It occupies the position of the somatic efferent column and therefore lies ventrally to the dorsal nucleus of the vagus (fig. 831). The fibres run forwards through the medulla oblongata, and emerge through the anterolateral sulcus between the pyramid and the olive (fig. 824).

The rootlets of the hypoglossal nerve run laterally behind the vertebral artery, and are collected into two bundles, which perforate the dura mater separately opposite the hypoglossal (anterior condylar) canal in the occipital bone, and unite together after their passage through it; in some cases the canal is divided into two by a small bony spicule. The fact that each bundle acquires a separate sheath from the dura mater is confirmatory evidence of the composite character of the nerve. On emerging from its canal the nerve lies on a deeper plane than the internal jugular vein, the internal carotid artery, the ninth, tenth and eleventh cranial nerves. It passes laterally, with a downward inclination, behind the internal carotid artery and the glossopharyngeal and vagus nerves to gain the interval between the artery and the internal jugular vein. In this part of its course it makes a half-spiral turn round the inferior ganglion of the vagus, to which it is united by a mass of connective tissue. It then descends almost vertically, lying between the vessels and in front of the vagus nerve, to a point corresponding with the angle of the mandible, and becomes superficial below the posterior belly of the digastric muscle, emerging from between the internal jugular vein and the internal carotid artery. The nerve then loops round the lower sternomastoid branch of the occipital artery (p. 745) and, having crossed the internal and external carotid arteries, it crosses the loop of the lingual artery a little above the tip of the greater cornu of the hyoid bone (fig. 955), being itself crossed by the facial vein. It inclined upwards as it runs forwards on the hyoglossus muscle, passing deep to the tendon of the digastric, the stylohyoid and the posterior border of the mylohyoid muscle. In the interval between the hyoglossus and mylohyoid muscles the nerve is related above to the deep part of the submandibular gland, the submandibular duct and the lingual nerve. It passes next on to the lateral aspect of the genioglossus and is continued forwards in its substance as far as the tip of the tongue, distributing branches to the muscle.

The hypoglossal nerve *communicates* with the sympathetic trunk, and with the vagus, first and second cervical, and lingual nerves.

Opposite the atlas the nerve receives branches from the superior cervical ganglion of the sympathetic trunk, and at the same level is joined by a filament from the loop connecting the first and second cervical nerves. This filament soon leaves the hypoglossal and descends as the *upper root* of the *ansa cervicalis* (*vide infra*).

The communications with the vagus nerve take place close to the skull, numerous filaments passing between the hypoglossal nerve and the inferior ganglion of the vagus nerve through the mass of connective tissue which unites them. As the nerve winds round the occipital artery it receives a filament from the pharyngeal plexus, which is termed the *ramus lingualis vagi* (p. 1132).

Near the anterior border of the hyoglossus it is connected with the lingual nerve by numerous filaments which ascend upon the muscle.

The *branches of distribution* of the hypoglossal nerve are :

Meningeal.
Descending.

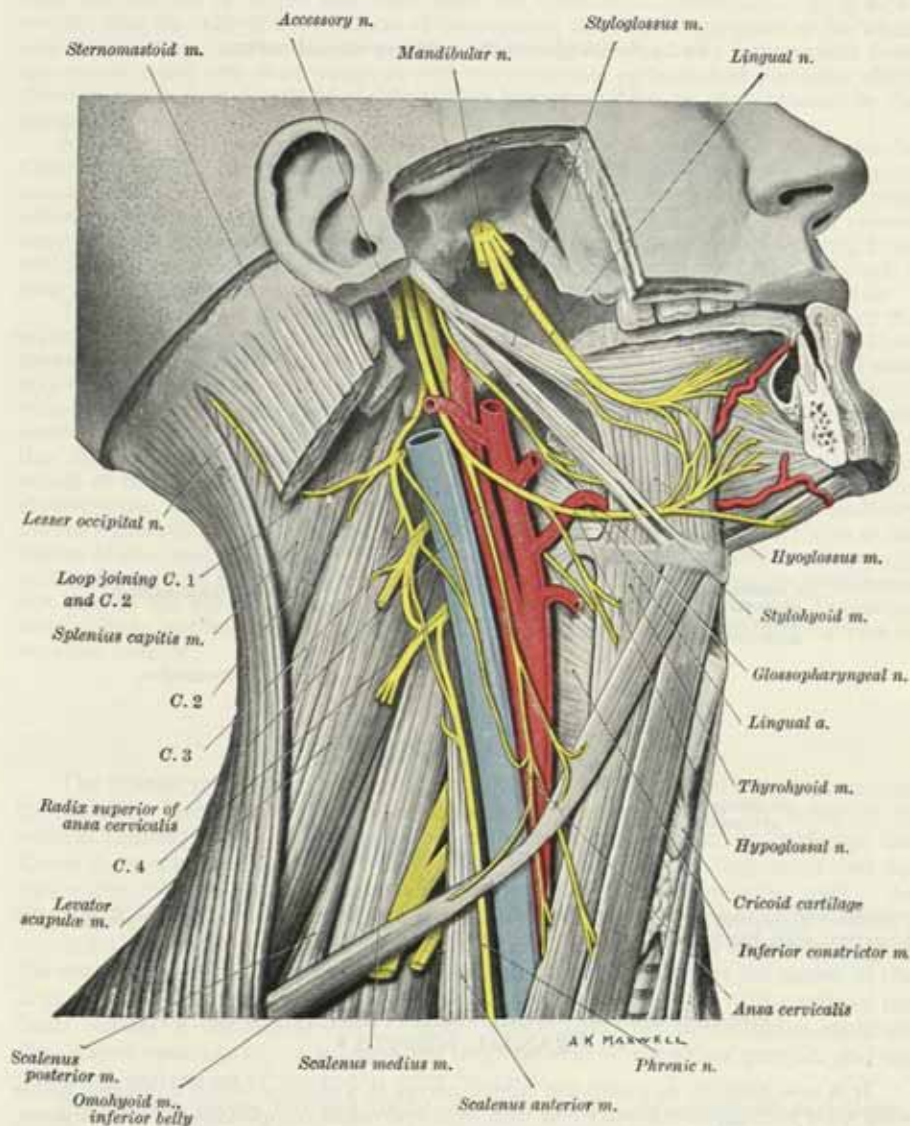
Thyrohyoid.
Muscular.

Meningeal branches.—As the hypoglossal nerve passes through the hypoglossal canal it gives off a recurrent branch which is distributed to the diploë of the occipital bone and to the walls of the occipital sinus.

The **descending branch** leaves the hypoglossal nerve where the latter turns round the occipital artery, and descends in front of or within the sheath of the carotid vessels. It contains no fibres from the hypoglossal nucleus, but only fibres from C₁, which constitute the upper root of the *ansa cervicalis*. After giving a branch to

the superior belly of the omohyoid muscle, this nerve is joined by the nervus descendens cervicalis from the second and third cervical nerves. The union of the two forms a loop, which is termed the *ansa cervicalis* but was long known as the *ansa hypoglossi*. From the convexity of this loop branches pass to supply the sternohyoid, the sternothyroid and the inferior belly of the omohyoid muscle. Another filament has been described which descends in front of the vessels into the thorax, and joins the cardiac and phrenic nerves.

FIG. 955.—A dissection to show the general distribution of the right hypoglossal nerve, and the position, constitution and some of the branches of the cervical plexus of the right side.



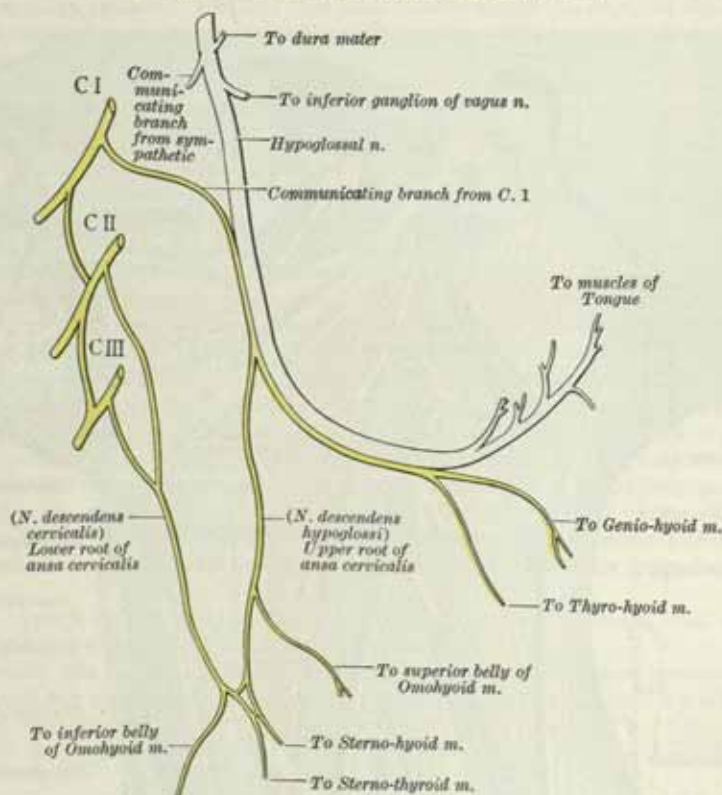
The nerve to the thyrohyoid arises from the hypoglossal nerve near the posterior border of the hyoglossus; it runs obliquely across the greater cornu of the hyoid bone, and supplies the thyrohyoid muscle.

The muscular branches are distributed to the styloglossus, hyoglossus, geniohyoid and genioglossus muscles. Numerous slender branches pass upwards into the substance of the tongue to supply its intrinsic muscles.

Applied Anatomy.—The hypoglossal nerve is an important guide in the operation of ligature of the lingual artery. It runs forwards on the hyoglossus just above the

greater cornu of the hyoid bone, and forms the upper boundary of the triangular space in which the artery is to be sought by cutting through the fibres of the hyoglossus. In cases where the nerve is involved by gumma or new growth of the base of the skull, or where it has been injured on one side of the neck, or in some cases of bulbar paralysis, unilateral paralysis, together with hemiatrophy of the tongue, results; the tongue, when protruded, being directed to the paralysed side owing to the unopposed action of the muscles of the opposite side. On retraction, the wasted and paralysed side of the tongue rises up higher than the other. The larynx may deviate towards the sound side on swallowing, from the unilateral paralysis of the depressors of the hyoid bone. If the paralysis is bilateral, e.g. the result of a bullet wound of the suprahyoid region, the tongue lies motionless in the mouth; taste and tactile sensibility of the organ are perfect, articulation is slow and sticky; swallowing is very difficult, and the

FIG. 956.—A plan of the right hypoglossal nerve.



patient has to throw his head backwards and push the bolus of food back into the pharynx with his finger before he can swallow it.

THE MORPHOLOGICAL RELATIONSHIPS OF THE CRANIAL NERVES *

It is now possible to group the cranial nerves in a manner which conforms better with their phylogenetic history and with their individual components. At least three, probably four, and possibly five groups are necessary.

Group I includes the third, fourth, sixth and twelfth cranial nerves. These all arise from the cells of the somatic efferent column, and they are distributed to the musculature derived from the cranial myotomes. They correspond, therefore, to the ventral nerve-roots of the spinal nerves, and with the exception of the fourth, they emerge from the brain-stem, in line with them. The identification of the individual segments with which each nerve is associated is a matter of considerable difficulty and is not susceptible of proof in the present state of our knowledge, for the precise number of segments represented by the head is still uncertain (p. 123).

* For Analysis of the Cranial Nerves, see pp. 1142-1143.

Group II includes the fifth, seventh, ninth, tenth and eleventh cranial nerves. These nerves were concerned with the innervation of the branchial arches, and they are placed in series with the nerve-roots of the spinal nerves. They differ from the latter in possessing motor roots which are distributed to the musculature derived from the neural crest (p. 128) and the lateral mesodermic plates of the branchial region. Some of these cranial nerves (the fifth, tenth and eleventh), are compound nerves and have been formed by the fusion of two or more dorsal nerves (p. 1088). In the process cutaneous branches, originally connected with the seventh, ninth and tenth nerves, have been taken over by the fifth, so that these nerves in man bear but little resemblance to their homologues in the lower forms of vertebrates and still less to the dorsal nerve-roots of the spinal nerves.

On account of the complexity of their components, each nerve may possess more than one nucleus of origin and more than one nucleus of termination. It is noteworthy that the cells of the ganglion of the seventh, the inferior ganglion of the ninth and the inferior ganglion of the tenth nerve, though derived to a large extent from the neural crest, owe their origin in part to ectodermal epibranchial placodes which develop at the dorsal ends of the first three branchial clefts in close relation to the ganglia (p. 144).

Although there are certain difficulties in the way, the homologies of the nerves in Groups I and II are generally accepted, but the allocation of the three remaining cranial nerves is entirely uncertain. On account of its mode of development, the optic nerve is usually regarded as having nothing in common with any of the other cranial nerves except its function as a special somatic afferent. The cells of the retina, from which its fibres are derived, really constitute an outlying part of the brain, although it may be urged that they are derivatives of the forerunners of the neural crest cells.

The olfactory and the eighth nerves may be grouped together or separately, or the eighth nerve may be regarded as being homologous with a dorsal nerve. Both nerves arise, in part at least, from ectodermal cells outside the area of the neural tube and crest, but whereas the olfactory cells remain intercalated amongst the epithelial cells of the nasal mucous membrane, the auditory cells migrate a short distance away from the otic vesicle. It must be explained, however, that many authorities believe that the contribution made by the neural crest is responsible for the formation of the whole of the eighth nerve ganglion, and on this account they prefer to regard the statoacoustic as a modified dorsal nerve. In comparing the olfactory and auditory nerves it must be remembered that the olfactory nerves are restricted in all forms to the region of the head, whereas the auditory nerve in man is the sole survivor of a whole series of nerves of the organs of the lateral line, which in lower forms are distributed not only to the head but also to the whole length of the trunk. There is, therefore, considerable justification for the allocation of the olfactory and statoacoustic nerves to separate groups.

THE SPINAL NERVES

The **spinal nerves** arise in series from the sides of the spinal cord and emerge through the intervertebral foramina. Each nerve is formed by the union of an ventral (motor) and a dorsal (sensory) nerve-root, but these roots perforate the spinal dura mater independently before they unite (fig. 922), an indication that the two nerve-roots originally remain separate throughout their course (p. 1088). As they emerge from the intervertebral foramina the spinal nerves obviously possess a segmental character, but this feature is much less conspicuous in the connexions of the nerve-roots with the spinal cord. The ventral nerve-roots are the axons of the large motor cells of the anterior grey column, and are derivatives of the cells of the basal lamina of the neural tube. On the other hand, the dorsal nerve-roots are the central branches of the axons of the unipolar cells of the spinal ganglia, and are therefore derivatives of the neural crest (p. 128).

The spinal nerves number thirty-one pairs, which are grouped as follows: cervical, 8; thoracic, 12; lumbar, 5; sacral, 5; coccygeal, 1. The abbreviations C., T., L., S. and Co., followed by the appropriate numeral, are commonly used to identify the individual nerves.

The first cervical nerve emerges from the vertebral canal between the occipital bone and the atlas vertebra, and is therefore called the *suboccipital nerve*; the eighth issues between the seventh cervical and first thoracic vertebrae.

Nerve-roots.—Each nerve is attached to the spinal cord by a ventral and a dorsal root (p. 945), the latter being characterised by the presence of a ganglion, which is termed the *spinal ganglion*.

(Continued on p. 1144.)

ANALYSIS OF THE CRANIAL NERVES

NERVE	COMPONENTS	FUNCTION	CELLS OF ORIGIN	PRINCIPAL CENTRAL CONNEXIONS
Olfactory	Special somatic (? and visceral) afferent	Smell	In nasal mucous membrane	(a) Olfactory bulb (b) Anterior perforated substance and piriform area
Optic	Special somatic afferent	Sight	Ganglionic layer of retina	(a) Lateral geniculate body (b) Visuosensory cortex (area 17)
Oculomotor	Somatic efferent General visceral efferent	Movements of eyeball Contraction of pupil Accommodation	III. nucleus Edinger-Westphal nucleus	Middle frontal gyrus (area 6) Preectal nucleus
Trochlear	General somatic afferent	Proprioceptive (muscles of eyeball)	?	(a) Thalamus (b) Postcentral gyrus (areas, 3, 1, 2) (c) ? Middle frontal gyrus (area 6)
Trigeminal	Somatic efferent General somatic afferent	Movements of eyeball Proprioceptive (Superior oblique muscle of eyeball)	IV. nucleus ?	Middle frontal gyrus (area 6) (a) Thalamus (b) Postcentral gyrus (areas, 3, 1, 2)
	Branchial (special visceral) efferent General somatic afferent	Movements of mandible (i) General sensibility of skin, mucous membrane, etc. (a) Painful and thermal (b) Tactile and pressure (ii) Proprioceptive (Muscles of mastication)	Motor nucleus of V.	Precentral gyrus (area 4)
Abducent	Somatic efferent General somatic afferent	Lateral movement of eyeball Proprioceptive (lateral rectus muscle)	VI. nucleus ?	(a) Nucleus of tractus spinalis (b) Thalamus (c) Postcentral gyrus (areas, 3, 1, 2) (a) Superior sensory nucleus of V. (b) Thalamus (c) Postcentral gyrus (areas, 3, 1, 2) (a) Thalamus (b) Postcentral gyrus (areas, 3, 1, 2)
Facial	Branchial (special visceral) efferent General visceral efferent	Facial expression and elevation of hyoid bone Secretomotor and vasodilator to submandibular and sublingual salivary glands and to lacrimal gland	VII. nucleus Superior salivary nucleus Lacrimal nucleus	Middle frontal gyrus (area 6) (a) Thalamus (b) Postcentral gyrus (areas, 3, 1, 2) Precentral gyrus (area 4)
	General somatic afferent Special visceral afferent	Proprioceptive (facial muscles, etc.) Taste; anterior two-thirds of tongue	Facial ganglion Facial ganglion	(a) Thalamus (b) Postcentral gyrus (areas, 3, 1, 2) (a) Nucleus of tractus solitarius (b) Thalamus (c) Postcentral gyrus (areas, 3, 1, 2)

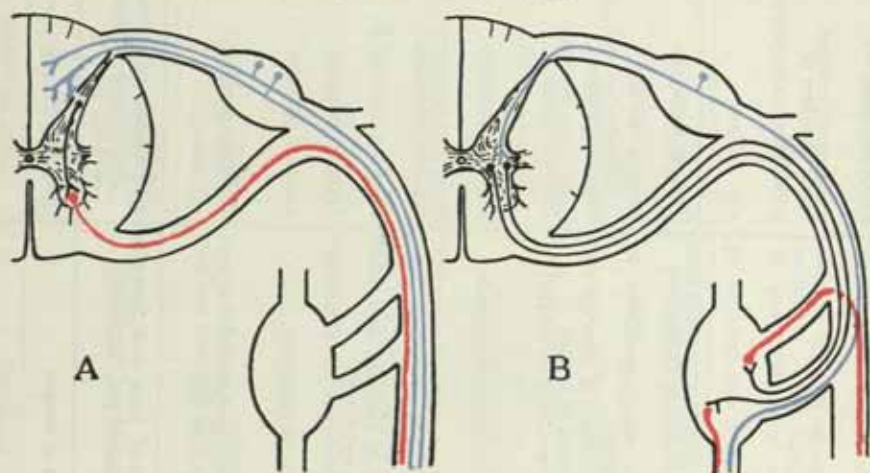
Statoacoustic (eighth) Vestibular	General somatic afferent (modified)	Equilibration	Vestibular ganglion	(a) Vestibular nuclei (b) Cerebellum, flocculo-nodular lobe
Cochlear	Special somatic afferent	Hearing	Spiral ganglion of cochlea	(a) Cochlear nuclei, of both sides (b) Medial geniculate body and inferior quadrigeminal body (c) Auditory cortex (<i>areas, 41, 42</i>) (d) Auditory cortex (<i>area, 22</i>)
				Precentral gyrus (<i>area, 4</i>)
Glossopharyngeal	Branchial (special visceral) efferent	Elevation of larynx in deglutition	Nucleus ambiguus	?
	General visceral efferent	Secretomotor and vasodilator to parotid gland	Inferior salivary nucleus	?
	General visceral afferent	Mucous membrane of pharynx and posterior third of tongue	Inferior ganglion	(a) Nucleus of tractus solitarius (b) Thalamus
	Special visceral afferent	Taste (posterior third of tongue)	Inferior ganglion	(c) Postcentral gyrus (<i>areas, 3, 1, 2</i>)
	General somatic afferent	Proprioceptive (stylopharyngeus muscle)	Superior ganglion	(a) Thalamus (b) Postcentral gyrus (<i>areas, 3, 1, 2</i>)
				Precentral gyrus (<i>area, 4</i>)
	Branchial (special visceral) efferent	Movements of deglutition and phonation	Nucleus ambiguus	?
	General visceral efferent	Movements of stomach and small intestine, <i>see p. 1188</i>	Dorsal nucleus of X.	Posterior orbital gyrus (<i>area 13</i>)
	General visceral afferent	Mucous membrane of alimentary canal, etc.	Inferior ganglion	(a) ? Nucleus of tractus solitarius (b) Frontal area
	Special visceral afferent	Taste (region of epiglottis)	Inferior ganglion	(a) Nucleus of tractus solitarius (b) Thalamus
Vagus and cranial root of Accessory	General somatic afferent	General cutaneous sensibility of part of auricle and external auditory meatus	Superior ganglion	(c) Postcentral gyrus (<i>areas, 3, 1, 2</i>) (a) ? Nucleus of spinal tract of V. (b) Thalamus (c) Postcentral gyrus (<i>areas, 3, 1, 2</i>)
				Precentral gyrus (<i>area 4</i>)
Accessory (spinal part)	Branchial (special visceral) efferent	Movements of head and shoulder (sternomastoid and trapezius)	Lateral part of anterior grey column of spinal cord (C. 1-C. 5)	Precentral gyrus (<i>area 4</i>)
Hypoglossal	Somatic efferent	Movements of tongue	XII. nucleus	Precentral gyrus (<i>area 4</i>)

The **ventral (anterior) root** emerges from the anterior surface of the spinal cord as a number of rootlets or filaments, which coalesce to form two bundles near the intervertebral foramen.

The **dorsal (posterior) root** (except that of the first cervical nerve) is larger than the ventral; its rootlets are attached along the posterolateral furrow of the spinal medulla and unite to form two bundles, which join the spinal ganglion.

The **spinal ganglia** are collections of nerve-cells on the dorsal roots of the spinal nerves. Each ganglion is oval in shape, reddish in colour, and its size bears a proportion to that of the nerve-root on which it is situated; it is bifid medially where it is joined by the two bundles of the dorsal nerve-root. The ganglia are usually placed in the intervertebral foramina, immediately outside the points where the nerve-roots perforate the dura mater (fig. 958), but the ganglia of the first and second cervical nerves lie on the vertebral arches of the atlas and axis, and those of the sacral nerves are inside the vertebral canal, and that of the coccygeal nerve is within the sheath of dura mater.

FIG. 957.—Diagrams of the central connexions of the somatic fibres (A) and sympathetic fibres (B) of a typical spinal nerve. Afferent fibres, blue; connector neurones, black, and efferent fibres, red.



The ganglia of the first pair of cervical nerves may be absent, while small *aberrant ganglia* consisting of groups of nerve-cells are sometimes found on the dorsal roots of the upper cervical nerves between the spinal ganglia and the spinal medulla.

Each nerve-root receives a covering from the pia mater, and is loosely invested by the arachnoid mater, the latter being prolonged as far as the points where the roots pierce the dura mater. The two roots pierce the dura mater separately, each receiving a sheath from this membrane (fig. 922); where the roots join to form the spinal nerve this sheath is continuous with the epineurium of the nerve.

Size and direction.—The roots of the upper four *cervical* nerves are small; those of the lower four are large. The dorsal roots of the cervical nerves bear a proportion to the ventral of three to one, which is greater than in the other regions; their individual filaments are also larger than those of the ventral roots. The dorsal root of the first cervical is an exception to this, being smaller than the ventral root; in about eight per cent. of cases it is wanting. The roots of the first and second cervical nerves are short, and run nearly horizontally to their points of exit from the vertebral canal. From the third to the eighth cervical they are directed obliquely downwards, the obliquity and length of the roots successively increasing; the distance, however, between the level of attachment of any of these roots to the spinal medulla and the points of exit of the corresponding nerves never exceeds the height of one vertebra.

The roots of the *thoracic* nerves, with the exception of the first, are of small size, and the dorsal roots only slightly exceed the ventral in thickness. They increase successively in length, from above downwards, and, in the lower part of the thoracic

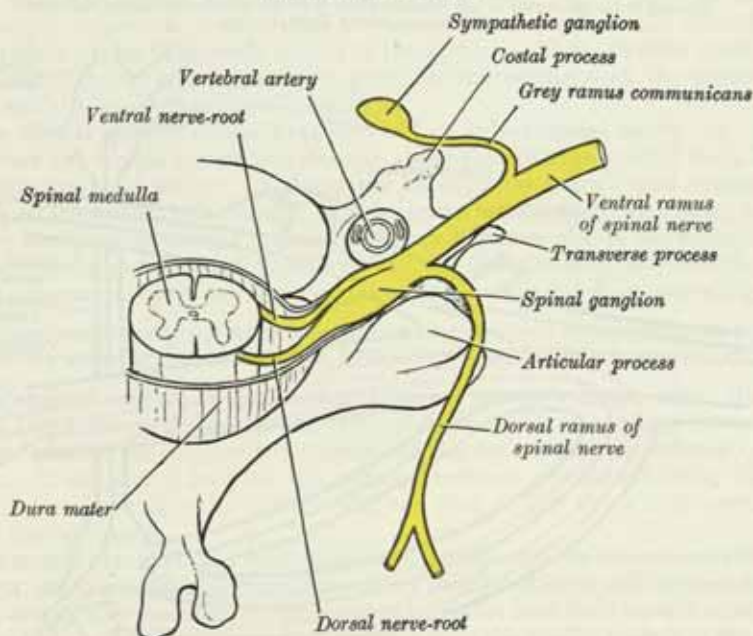
region, descend in contact with the spinal cord for a distance equal to the height of at least two vertebræ before they emerge from the vertebral canal.

The roots of the lower *lumbar* and upper *sacral* nerves are the largest, and their individual filaments the most numerous of all the spinal nerves, while the roots of the *coccygeal* nerve are the smallest.

The roots of the lumbar, sacral, and coccygeal nerves run vertically downwards to their respective exits, and as the spinal medulla ends near the lower border of the first lumbar vertebra it follows that the lengths of the successive roots must rapidly increase. As already mentioned (p. 931), the term *cauda equina* is applied to this collection of nerve-roots.

From the description given it will be seen that the largest nerve-roots, and consequently the largest spinal nerves, are attached to the cervical and lumbar swellings of the spinal medulla; these nerves are distributed to the upper and lower limbs.

FIG. 958.—Scheme showing the relations of a cervical nerve and its ganglion to a cervical vertebra.



Immediately beyond the spinal ganglion, the ventral and dorsal nerve-roots unite to form the *spinal nerve*, which emerges through the intervertebral foramen.

Connexions with the sympathetic trunks.—After emerging from the intervertebral foramen each spinal nerve receives a branch (*grey ramus communicans*) from the corresponding ganglion of the sympathetic trunk, while all the thoracic, and the first and second lumbar nerves each contribute a branch (*white ramus communicans*) to the corresponding sympathetic ganglion. The second, third, and fourth sacral nerves also give off visceral branches; these, however, are not connected with the ganglia of the sympathetic trunk, but belong to the parasympathetic part of the autonomic system and run directly into the pelvic plexuses (p. 1219).

Components (figs. 957, 959).—Each typical spinal nerve contains fibres belonging to two systems, viz. the somatic or cerebrospinal, and the autonomic, as well as fibres connecting these systems with one another.

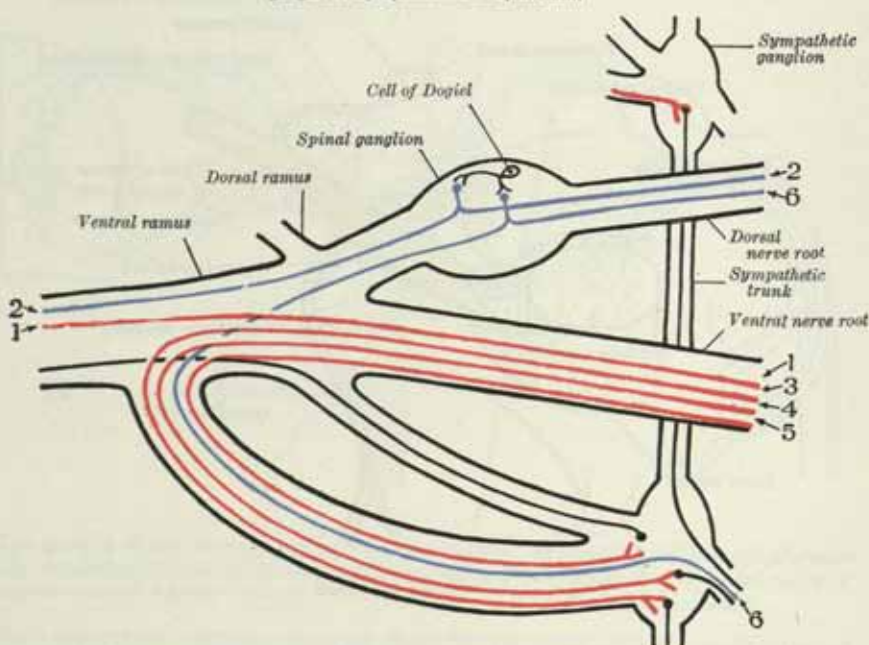
1. The *somatic efferent* fibres originate in the cells of the anterior grey column of the spinal medulla, and run outwards through the ventral nerve-roots to the spinal nerve. They convey impulses to the voluntary muscles, and are continuous from their origin to their peripheral distribution. The passage of a nervous impulse along a somatic efferent fibre is associated with the liberation of acetyl-choline in the neighbourhood of its terminals (p. 1199). The *somatic afferent* fibres convey

impressions inwards from the skin, etc., and originate in the unipolar nerve-cells of the spinal ganglia. The single processes of these cells divide into peripheral and central fibres, and the latter enter the spinal medulla through the dorsal nerve-roots.

2. The *autonomic* fibres are also efferent and afferent. The *efferent* fibres originate in the lateral column of the spinal cord, and are conveyed through the ventral nerve-roots and the white rami communicantes (fig. 959) of T. 1-L. 2 or 3. They pass to the corresponding ganglia of the sympathetic trunk and may end by forming synapses around the cells of the ganglia, or they may run through one ganglion to end in another on the sympathetic trunk, or in a more distally placed ganglion in one of the sympathetic plexuses. In all cases they end by forming synapses around other nerve-cells. From the cells of the ganglia of the sympathetic trunk other fibres (*postganglionic*) take origin; some of these run through the grey rami communicantes to join the spinal nerves and are distributed to the blood-vessels, sweat

FIG. 959.—A scheme showing the constitution of a typical spinal nerve.

Afferent fibres are shown in blue, efferent fibres from the spinal cord, in red, and post-ganglionic sympathetic fibres, in black.



1. Somatic efferent fibre. 2. Somatic afferent fibre. 3, 4, and 5. Efferent, pre-ganglionic, sympathetic fibres. 6. Afferent sympathetic fibre.

glands, etc.; others pass to the viscera. The fibres issuing from the sacral region of the spinal medulla (S. 2, 3 and 4) are *parasympathetic*; they do not join the sympathetic ganglia but pass as the *pelvic splanchnic nerves* to the pelvic plexuses. The *afferent* fibres are derived from the cells of the spinal ganglia. Their peripheral processes are carried through the white rami communicantes, and after passing without interruption through one or more sympathetic ganglia end in the tissues of the viscera. The central processes of the unipolar cells enter the spinal cord through the posterior nerve-roots and form synapses around either somatic or sympathetic efferent neurones, thus completing reflex arcs. Some authorities believe that the cells of Dogiel in the spinal ganglia (p. 1091) bring the autonomic afferent neurones into relationship with those of the somatic system, and so render possible the transference of an impulse from the former to the brain.

Rami or Divisions.—After emerging from the intervertebral foramen, each spinal nerve supplies a small *meningeal branch*, which re-enters the vertebral canal through the intervertebral foramen and is distributed to the vertebræ and their

ligaments, and the blood-vessels of the spinal medulla and its membranes. The spinal nerve then splits into a *dorsal* and a *ventral ramus*, each receiving fibres from both nerve-roots.

THE DORSAL RAMI OF THE SPINAL NERVES

The **dorsal (posterior primary) rami** of the spinal nerves are as a rule smaller than the *ventral*. They are directed backwards, and, with the exceptions of those of the first cervical, the fourth and fifth sacral, and the coccygeal, divide into medial and lateral branches for the supply of the muscles and skin (fig. 960) of the posterior part of the trunk.

THE DORSAL RAMI OF THE CERVICAL NERVES

The dorsal ramus of each cervical nerve, with the exception of the first, divides into a medial and a lateral branch. All these branches innervate muscles but, as a rule, only the medial branches of the second, third, fourth and, usually, the fifth, supply cutaneous areas. With the exception of the first and second, each dorsal ramus passes backwards medial to the posterior intertransverse muscle and winds round the articular process to gain the interval between the semispinalis capitis and the semispinalis cervicis muscles.

The **dorsal ramus of the first cervical or suboccipital nerve** (fig. 574) is larger than the ventral ramus, and emerges above the posterior arch of the atlas and below the vertebral artery. It enters the suboccipital triangle and supplies the muscles which bound this triangle, viz. the rectus capitis posterior major, and the superior and inferior oblique muscles; it gives branches also to the rectus capitis posterior minor and the semispinalis capitis. A filament from the branch of the inferior oblique muscle joins the dorsal ramus of the second cervical nerve (fig. 574).

The nerve occasionally gives off a cutaneous branch which accompanies the occipital artery to the scalp, and communicates with the greater and lesser occipital nerves.

The **dorsal ramus of the second cervical nerve** is much larger than the ventral, and is the greatest of all the cervical dorsal rami. It emerges between the posterior arch of the atlas and the lamina of the axis, below the inferior oblique muscle. It supplies a twig to this muscle, receives a communicating filament from the dorsal ramus of the first cervical, and then divides into a large medial and a small lateral branch.

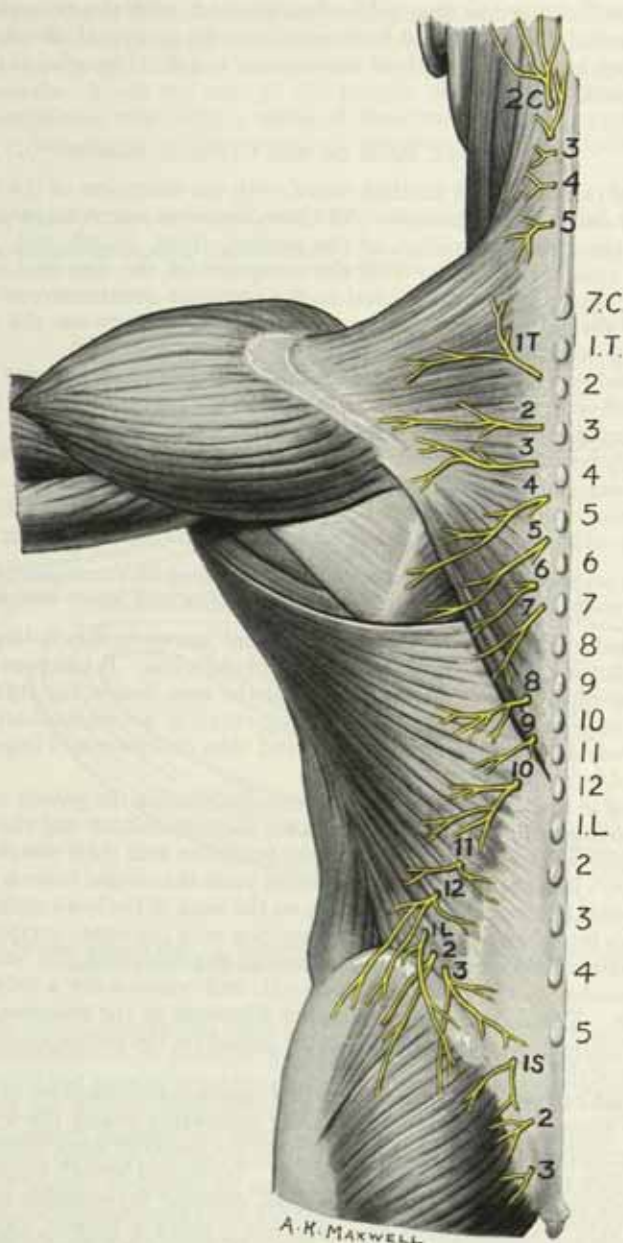
The *medial* branch, called from its size and distribution the *greater occipital nerve* (figs. 574, 960), ascends obliquely between the inferior oblique and the semispinalis capitis, and pierces the latter muscle and the trapezius near their attachments to the occipital bone. It is then joined by a filament from the medial branch of the dorsal ramus of the third cervical, and, ascending on the back of the head with the occipital artery, divides into branches which communicate with the lesser occipital nerve and supply the skin of the scalp as far forward as the vertex of the skull. It gives muscular branches to the semispinalis capitis, and occasionally a twig to the back of the auricle. The *lateral* branch supplies filaments to the splenius, longissimus capitis and semispinalis capitis, and is often joined by the corresponding branch of the third cervical.

The **dorsal ramus of the third cervical nerve** is intermediate in size between those of the second and fourth. It courses backwards round the articular pillar of the third cervical vertebra, passing medial to the posterior intertransverse muscle, and divides into medial and lateral branches. Its *medial* branch runs between the spinalis capitis and semispinalis cervicis, and, piercing the splenius and trapezius, ends in the skin. While under the trapezius it gives a branch, called the *third occipital nerve*, which pierces the trapezius and ends in the skin of the lower part of the back of the head (fig. 960). It lies medial to the greater occipital nerve, and communicates with it. The *lateral* branch often joins that of the second cervical.

The dorsal ramus of the suboccipital, and the medial branches of the dorsal rami of the second and third cervical nerves are sometimes joined by communicating loops to form the *posterior cervical plexus*.

The **dorsal rami of the lower five cervical nerves** curve backwards round the articular pillars and divide into medial and lateral branches. The *medial* branches of the fourth and fifth run between the semispinalis cervicis and semispinalis capitis, and, having reached the spines of the vertebræ, pierce the splenius

FIG. 960.—A diagram showing the distribution of the cutaneous branches of the dorsal rami of the spinal nerves.



and trapezius to end in the skin (fig. 960). Sometimes the medial branch of the fifth fails to reach the skin. The medial branches of the lowest three nerves are small, and end in the semispinalis cervicis, semispinalis capitis, multifidus and interspinales. The *lateral* branches of the lower five nerves supply the iliocostalis cervicis, longissimus cervicis, and longissimus capitis.

THE DORSAL RAMI OF THE THORACIC NERVES

The **dorsal rami of the thoracic nerves** pass backwards in close relation to the joints between the articular processes of the vertebræ and divide into medial and lateral branches. The medial branch emerges between the joint and the medial edge of the superior costotransverse ligament and the intertransverse muscle, but the lateral branch runs laterally in the interval between the ligament and the muscle before turning backwards medial to the levator costæ muscle.

The *medial branches of the dorsal rami of the upper six thoracic nerves* run between the semispinalis thoracis and multifidus, which they supply; they then pierce the rhomboids and trapezius, and reach the skin by the sides of the spines (fig. 960). The medial branches of the *lower six thoracic nerves* are distributed chiefly to the multifidus and longissimus thoracis; occasionally they give filaments to the skin near the median plane.

The *lateral branches* increase in size from above downwards. They run through or deep to the longissimus thoracis to the interval between it and the iliocostalis cervicis, and supply these muscles and the levatores costarum; the lower five or six also give off cutaneous branches, which pierce the serratus posterior inferior and latissimus dorsi in a line with the angles of the ribs (fig. 960). The lateral branches of a variable number of the upper thoracic nerves also give filaments to the skin. The lateral branch of the twelfth thoracic, after sending a filament medially along the iliac crest, passes downwards to the skin of the anterior part of the buttock.

The medial cutaneous branches of the dorsal rami of the thoracic nerves descend for some distance close to the spines before reaching the skin, while the lateral branches travel downwards for a considerable distance—it may be as much as the breadth of four ribs—before they become superficial; the branch from the twelfth thoracic, for instance, reaches the skin only a little way above the iliac crest.*

THE DORSAL RAMI OF THE LUMBAR NERVES

The **dorsal rami of the lumbar nerves** pass backwards medial to the medial intertransverse muscles and at once divide into medial and lateral branches.

The *medial branches* run close to the articular processes of the vertebræ and end in the multifidus.

The *lateral branches* supply the erector spinæ (sacrospinalis). The upper three give off cutaneous nerves which pierce the aponeurosis of the latissimus dorsi at the lateral border of the erector spinæ and cross the posterior part of the iliac crest to reach the skin of the buttock (fig. 960), some of their twigs running as far as the level of the greater trochanter.

THE DORSAL RAMI OF THE SACRAL NERVES

The **dorsal rami of the sacral nerves** are small, and diminish in size from above downwards; with the exception of the fifth, they emerge through the dorsal sacral foramina. The *upper three* are covered at their points of exit by the multifidus, and divide into medial and lateral branches.

The *medial branches* are small, and end in the multifidus.

The *lateral branches* join with one another and with the lateral branches of the dorsal rami of the last lumbar and fourth sacral to form loops on the dorsal surface of the sacrum. From these loops branches run to the dorsal surface of the sacrotuberous ligament and form a second series of loops under the gluteus maximus. From this second series of loops the *gluteal branches*, two or three in number, arise and at once pierce the gluteus maximus along a line drawn from the posterior superior iliac spine to the tip of the coccyx; they supply the skin over the posterior part of the buttock (fig. 960).

The dorsal rami of the *lower two* sacral nerves are small and lie below the multifidus. They do not divide into medial and lateral branches, but unite with each other and with the dorsal ramus of the coccygeal nerve to form loops on the back of the sacrum; filaments from these loops supply the skin over the coccyx.

* H. M. Johnston, *J. Anat. and Physiol.*, 43, 1908.

THE DORSAL RAMUS OF THE COCCYGEAL NERVE

The **dorsal ramus of the coccygeal nerve** does not divide into a medial and a lateral branch, but receives, as already stated, a communicating branch from the last sacral; it is distributed to the skin over the back of the coccyx.

THE VENTRAL RAMI OF THE SPINAL NERVES

The **ventral rami of the spinal nerves** supply the limbs and the anterior and lateral aspects of the trunk; they are for the most part larger than the dorsal rami. In the thoracic region they run independently of one another, retaining, like all the dorsal rami, a more or less segmental distribution. In the cervical, lumbar, and sacral regions, however, they unite near their origins to form plexuses.

THE VENTRAL RAMI OF THE CERVICAL NERVES

The **ventral rami of the cervical nerves**, with the exception of the first, appear between the corresponding anterior and posterior intertransverse muscles. The ventral rami of the *upper four* nerves unite to form the *cervical plexus*; those of the *lower four*, together with the greater part of the ventral ramus of the first thoracic nerve, join to form the *brachial plexus*.

Each nerve receives at least one grey ramus communicans, the upper four from the superior cervical ganglion, the fifth and sixth from the middle cervical ganglion, and the seventh and eighth from the inferior cervical ganglion of the sympathetic trunk (*see p. 1209*).

The ventral ramus of the *first cervical (suboccipital) nerve* appears above the posterior arch of the atlas vertebra, and passes forwards round the lateral side of its lateral mass, medial to the vertebral artery. It supplies a branch to the rectus lateralis, and, emerging on the medial side of that muscle, descends in front of the transverse process of the atlas and behind the internal jugular vein, and joins with the ascending branch of the second nerve.

The ventral ramus of the *second cervical nerve* issues between the vertebral arches of the atlas and axis and runs forwards between the transverse processes of these two vertebrae; passing in front of the first posterior intertransverse muscle and on the lateral side of the vertebral artery it emerges between the longus capitis and levator scapulae muscles, but when the scalenus medius takes origin from the transverse process of the atlas, it intervenes between the nerve and the levator scapulae. It divides into an ascending branch which joins with the first cervical nerve, and a descending branch which unites with the ascending branch of the third cervical nerve.

The ventral ramus of the *third cervical nerve* appears between the longus capitis and scalenus medius. The ventral rami of the remaining cervical nerves emerge between the scalenus anterior and scalenus medius.

THE CERVICAL PLEXUS

The **cervical plexus** (*fig. 961*) is formed by the ventral rami of the upper four cervical nerves; each nerve, except the first, divides into an upper and a lower branch, and these unite to form three loops. The plexus is situated opposite the upper four cervical vertebrae, in front of the levator scapulae and scalenus medius, and under cover of the internal jugular vein and the sternomastoid muscle.

Its branches are divided into two groups, *superficial* and *deep*, and are here given in tabular form:

Superficial	Lesser occipital	.	.	.	.	2 C.
	Great auricular	.	.	.	.	2, 3 C.
	Transverse (Anterior) cutaneous	.	.	.	.	2, 3 C.
	Supraclavicular	.	.	.	.	3, 4 C.

Deep	Medial	Communicating	With hypoglossal	1, 2 C.
			„ vagus	1, 2 C.
			„ sympathetic	1, 2, 3, 4 C.
			Rectus capitis lateralis	1 C.
			Rectus capitis anterior	1, 2 C.
	Muscular		Longus capitis	1, 2, 3 C.
			Longus cervicis	2, 3, 4 C.
			Inferior root of ansa cervicalis	2, 3 C.
			Phrenic	3, 4, 5 C.
				2, 3, 4 C.
Lateral	Communicating	with accessory	Sternomastoid	2 C.
			Trapezius	3, 4 C.
	Muscular		Levator scapulae	3, 4 C.
			Scalenus medius	3, 4 C.
				3, 4 C.

It should be noted that the communicating branch to the hypoglossal nerve carries the motor fibres for the geniohyoid and thyrohyoid muscles and constitutes the superior root of the *ansa cervicalis*.

THE SUPERFICIAL BRANCHES OF THE CERVICAL PLEXUS (figs. 961, 962)

The **lesser occipital nerve** (figs. 961, 962) arises from the second cervical nerve, sometimes also from the third; it hooks around the accessory nerve and ascends along the posterior border of the sternomastoid muscle. Near the cranium it perforates the deep fascia, and is continued upwards on the side of the head behind the auricle, supplying the skin and communicating with the great auricular and greater occipital nerves, and with the posterior auricular branch of the facial nerve. The lesser occipital nerve varies in size, and is sometimes duplicated.

It sends off an *auricular branch* which supplies the skin of the upper third of the cranial surface of the auricle, and communicates with the posterior branch of the great auricular nerve. The auricular branch is occasionally derived from the greater occipital nerve.

The **great auricular nerve** (figs. 961, 962) is the largest of the ascending branches. It arises from the second and third cervical nerves, winds round the posterior border of the sternomastoid muscle, and, after perforating the deep fascia, ascends upon that muscle beneath the platysma in company with the external jugular vein. It passes on to the parotid gland, where it divides into an anterior and a posterior branch.

The *anterior branch* is distributed to the skin of the face over the parotid gland, and communicates in the substance of the gland with the facial nerve.

The *posterior branch* supplies the skin over the mastoid process and on the back of the auricle, except at its upper part; a filament pierces the auricle to reach its lateral surface, where it is distributed to the lobule and the concha. The posterior branch communicates with the lesser occipital nerve, the auricular branch of the vagus nerve, and the posterior auricular branch of the facial nerve.

The **transverse (anterior) cutaneous nerve of the neck** (figs. 961, 962) arises from the second and third cervical nerves, turns round the posterior border of the sternomastoid about its middle, and runs obliquely forwards, deep to the external jugular vein, to the anterior border of the muscle. It perforates the deep cervical fascia, and divides beneath the platysma into ascending and descending branches, which are distributed to the anterolateral parts of the neck.

The *ascending branches* pass upwards to the submandibular region, and form a plexus with the cervical branch of the facial nerve, beneath the platysma; others pierce that muscle, and are distributed to the skin of the upper and front parts of the neck.

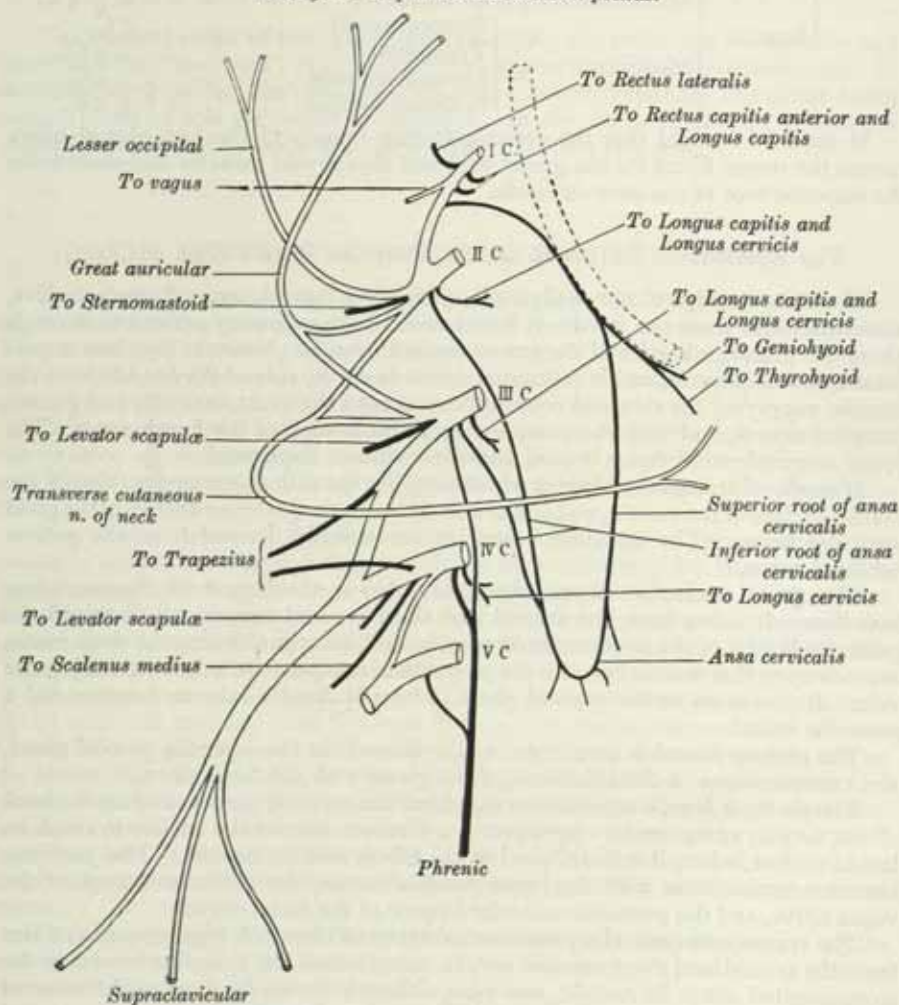
The *descending branches* pierce the platysma, and are distributed to the skin of the side and front of the neck, as low as the sternum.

The **supraclavicular nerves** (figs. 961, 962) arise by a common trunk derived from the third and fourth cervical nerves. This trunk emerges from beneath the posterior border of the sternomastoid, descends under cover of the platysma and deep cervical fascia, and divides into anterior, middle and posterior branches, which diverge from one another and pierce the deep fascia a little above the level of the clavicle.

The *anterior supraclavicular nerves* run obliquely downwards and medially, crossing the external jugular vein and the clavicular and sternal heads of the sternomastoid, to supply the skin as far as the median plane and as low down as the second rib. They furnish one or two filaments to the sternoclavicular joint.

The *middle supraclavicular nerves* cross the clavicle, and supply the skin over the pectoralis major and deltoid as low down as the level of the second rib, immediately adjoining the area supplied by the second thoracic nerve (fig. 987). The amount of overlapping in this situation is minimal.

FIG. 961.—A plan of the cervical plexus.



Note.—The hypoglossal nerve is shown by interrupted lines and the muscular branches by solid black lines.

The *posterior supraclavicular nerves* pass obliquely across the superficial surface of the trapezius and the acromion, and supply the skin of the upper and posterior parts of the shoulder.

Applied Anatomy.—Pains referred to the superficial terminal branches of the cervical plexus are not uncommon in caries of the cervical vertebræ, where pain may be felt radiating over the occipital bone, if the disease is situated high up in the vertebral column.

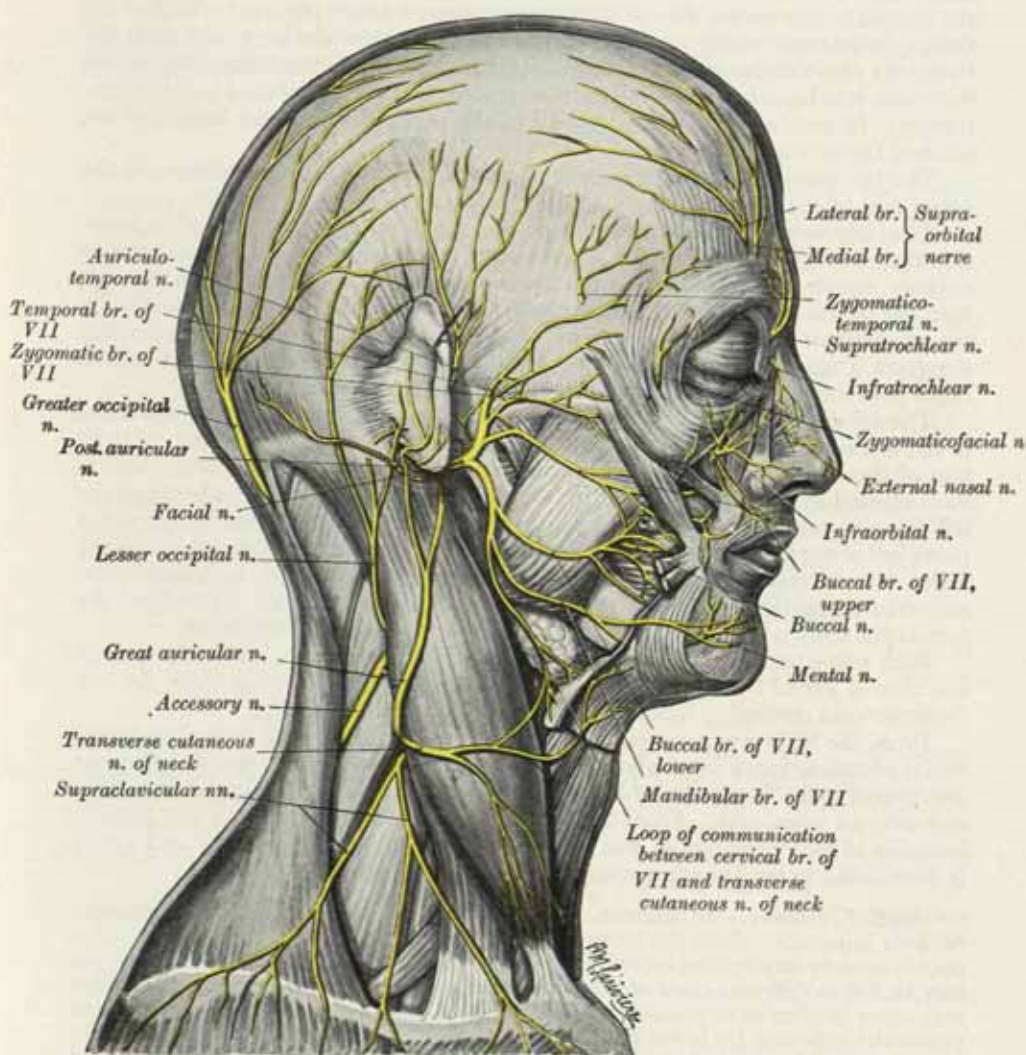
THE DEEP BRANCHES OF THE CERVICAL PLEXUS. MEDIAL SERIES

The **communicating branches** consist of several filaments which pass from the loop between the first and second cervical nerves to the vagus, hypoglossal and sympathetic. The branch to the hypoglossal ultimately leaves that nerve as a series

of branches, viz. the meningeal, the upper root of the ansa cervicalis (ansa hypoglossi), the nerve to the thyrohyoid and, probably, the nerve to the geniohyoid (p. 1139). A communicating branch also passes from the fourth to the fifth cervical nerve, while each of the first four cervical nerves receives as grey ramus communicans from the superior cervical ganglion of the sympathetic trunk.

Muscular branches supply the rectus capitis lateralis, rectus capitis anterior, longus capitis and longus cervicis muscles.

FIG. 962.—The nerves of the right side of the scalp, face and side of neck.



The **inferior root of the ansa cervicalis (nervus descendens cervicalis)** (fig. 961) is formed usually by the union of two branches, one derived from the second cervical nerve and the other from the third. It passes downwards on the lateral side of the internal jugular vein, crosses in front of this vein a little below the middle of the neck, and continues forwards to join the upper root in front of the common carotid artery, so forming the *ansa cervicalis*. Not infrequently it passes forwards between the internal jugular vein and the common carotid artery to reach the ansa cervicalis (fig. 686), from which all the infrahyoid muscles, with the exception of the thyrohyoid, are supplied.

The **phrenic nerve** contains motor and sensory fibres in the proportion of about two to one. It arises chiefly from the fourth cervical nerve, but receives a branch

from the third and another from the fifth (fig. 961); the fibres from the fifth not infrequently come through the nerve to the subclavius (p. 1157) and, after leaving it, they may descend for some distance into the thorax before joining the main trunk (*accessory phrenic nerve*). Formed at the upper part of the lateral border of the scalenus anterior, the phrenic nerve runs vertically downwards across the front of that muscle, and behind the prevertebral fascia. It descends to the root of the neck, under cover of the sternomastoid, the inferior belly of the omohyoid, the internal jugular vein and the transverse cervical and suprascapular arteries (fig. 704) and, on the left side, the thoracic duct. It next passes in front of the subclavian artery, between it and the subclavian vein, and, as it enters the thorax, crosses from the lateral, to the medial side of the internal thoracic artery (fig. 701). Within the thorax, it descends nearly vertically in front of the root of the lung, and then between the pericardium and the mediastinal pleura, to the diaphragm (fig. 767), where it divides into branches which pierce that muscle, and are distributed to its under-surface. In the thorax it is accompanied by the pericardiophrenic branch of the internal thoracic artery.

The two phrenic nerves differ in their length, and also in their relations at the upper part of the thorax.

The *right nerve* is situated more deeply, and is shorter and more vertical in direction than the left. It descends to a lower level in the neck in front of the scalenus anterior, which thus separates it from the second part of the subclavian artery. It then lies lateral to the right brachiocephalic vein and superior vena cava covered by the mediastinal pleura, and continues downwards over the pericardium which separates it from the right wall of the right atrium of the heart. Its terminal fibres pass through the vena caval opening in the diaphragm.

The *left nerve* is rather longer than the right, owing to the inclination of the heart to the left side, and to the lower level of the left half of the diaphragm. At the root of the neck it crosses in front of the first part of the subclavian artery, and is itself crossed by the thoracic duct. In the superior mediastinum it lies between the left common carotid and left subclavian arteries, and crosses superficial to the vagus nerve just above the level of the arch of the aorta and behind the left brachiocephalic vein. It next crosses the arch of the aorta and the left superior intercostal vein and then passes in front of the root of the left lung to reach the left side of the pericardium, by which it is separated from the left ventricle of the heart.

Each nerve supplies branches to the pericardium and pleura, and at the root of the neck is joined by a filament from the sympathetic, and, occasionally, by one from the ansa cervicalis, which probably is sympathetic in origin.

From the *right nerve*, one or two filaments pass with phrenic branches of the celiac plexus to join a small *phrenic ganglion*; and branches from this ganglion are distributed to the falciform and coronary ligaments of the liver, the suprarenal gland and inferior vena cava. From the *left nerve*, filaments pass to join the phrenic branches of the celiac plexus, but without any ganglionic enlargement; and a twig is distributed to the left suprarenal gland.

Applied Anatomy.—In addition to its supply from the phrenics, the diaphragm receives innervation from the lower seven intercostal nerves at its periphery. This double sensory innervation explains the varied distribution of the referred pains that may be felt in different cases of infection or inflammation of the diaphragm, such as may occur in pleurisy or pneumonia affecting its upper surface, on the one hand, or in peritonitis attacking its lower surface on the other. For example, if it is the more central part of the diaphragm that becomes inflamed in a case of acute peritonitis, the patient may complain of pain and tenderness in the area of distribution of the cutaneous branches of the fourth and fifth cervical nerves, with the result that disease of the shoulder-joint or supraclavicular region is erroneously suspected, and the peritonitis is missed. On the other hand, if the periphery of the diaphragm chances to become infected in a patient with acute pleurisy or pneumonia, he may complain of acute pain and tenderness in the area of distribution of the cutaneous branches of the lower intercostal nerves, and may also exhibit rigidity of the underlying abdominal muscles, with the result that an acute intra-abdominal infection may be erroneously diagnosed and a laparotomy performed for the relief of a supposed appendicitis, cholecystitis or localised peritonitis.

THE DEEP BRANCHES OF THE CERVICAL PLEXUS. LATERAL SERIES

Communicating branches.—The lateral series of deep branches of the cervical plexus communicates with the accessory nerve, in the substance of the sternomastoid, in the posterior triangle and under cover of the trapezius.

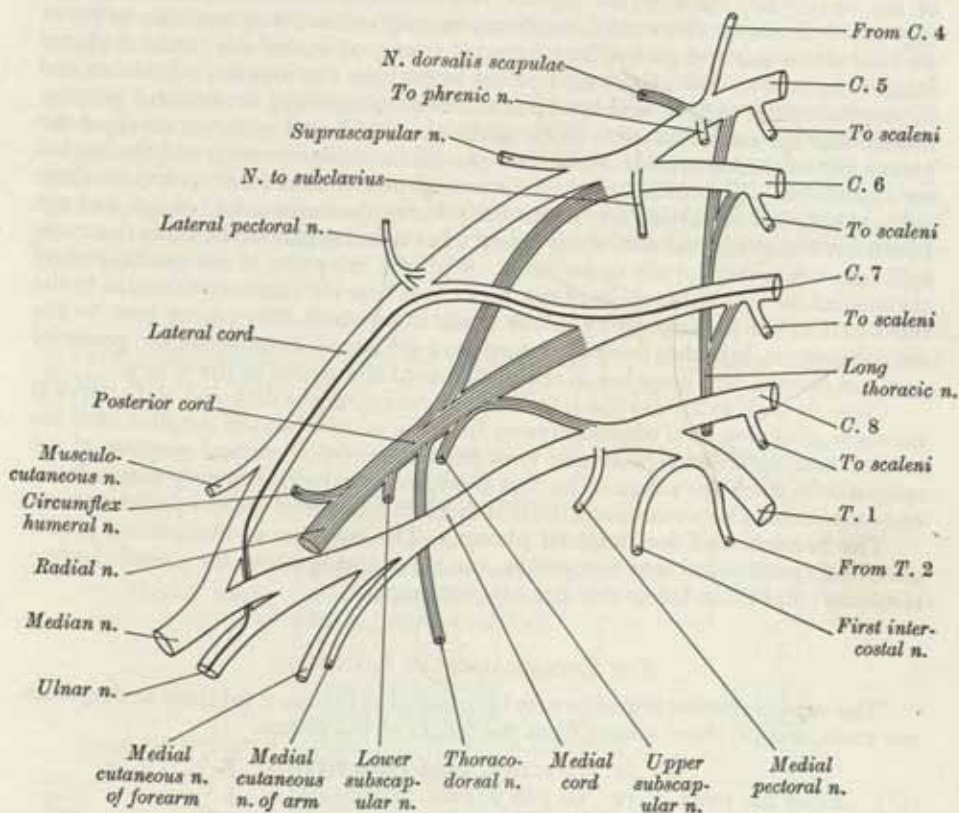
Muscular branches are distributed to the sternomastoid, trapezius, levator scapulæ and scalenus medius muscles.

The branch for the sternomastoid is derived from the second cervical nerve; the trapezius and levator scapulae receive branches from the third and fourth cervical nerves, those to the trapezius crossing the posterior triangle obliquely at a lower level than the accessory nerve. The scalenus medius receives twigs either from the third or fourth cervical nerves, or occasionally from both.

THE BRACHIAL PLEXUS

The **brachial plexus** (fig. 963) is formed by the union of the ventral rami of the lower four cervical nerves and the greater part of the ventral

FIG. 963.—A plan of the brachial plexus.



Note.—The posterior divisions of the trunks and their derivatives are shaded and the fibres from C.7 which run with the ulnar nerve are shown as a heavy block line.

ramus of the first thoracic nerve; the fourth cervical nerve usually gives a branch to the fifth cervical, and the first thoracic nerve frequently receives one from the second thoracic.* These nerves constitute the *roots* of the plexus. The roots are

* The contributions made to the plexus by C₄ and T₂ are subject to frequent variation. When the branch from C₄ is large, the branch from T₂ is frequently absent and the branch from T₁ is reduced in size. This constitutes the *prefixed type* of plexus. On the other hand the branch from C₄ may be very small or entirely absent. In that event the contribution of C₅ is reduced in size but that of T₁ is large and the branch from T₂ is always present. This arrangement constitutes the *post-fixed type* of plexus.

nearly equal in size, but the way in which they form the plexus is subject to some variation. The following is, however, the most constant arrangement. The fifth and sixth cervical nerves unite at the lateral border of the scalenus medius to form the *upper trunk* of the plexus. The eighth cervical and first thoracic nerves unite behind the scalenus anterior to form the *lower trunk* of the plexus, while the seventh cervical nerve itself constitutes the *middle trunk*. These three trunks run downwards and laterally and as—sometimes before—they pass behind the clavicle, each splits into an *anterior* and a *posterior division*.* The anterior divisions of the upper and middle trunks unite to form a cord, which is situated on the lateral side of the axillary artery, and is called the *lateral cord* of the plexus. The anterior division of the lower trunk passes down at first behind and then on the medial side of the axillary artery, and forms the *medial cord* of the brachial plexus; this cord frequently receives fibres from the seventh cervical nerve. The posterior divisions of all three trunks unite to form the *posterior cord* of the plexus, which is situated at first above and then behind the axillary artery.

Relations.—*In the neck*, the brachial plexus lies in the posterior triangle in the angle between the clavicle and the lower part of the posterior border of the sternomastoid, being covered by the skin, platysma and deep fascia. When the arm is by the side, it can be felt in this situation as a bunch of tense cords. The plexus is crossed by the supraclavicular nerves, the nerve to the subclavius, the inferior belly of the omohyoid, the external jugular vein and the transverse cervical artery (fig. 704). It emerges between the scalenus anterior and scalenus medius; its upper part lies above the third part of the subclavian artery, while the lower trunk is placed behind the artery; the plexus next passes behind the clavicle, the subclavius and the suprascapular vessels, and lies upon the first digitation of the serratus anterior muscle and the subscapularis. *In the axilla* the lateral and posterior cords of the plexus are on the lateral side of the first part of the axillary artery, and the medial cord behind it. The cords surround the second part of the axillary artery on three sides, the medial cord lying on the medial side, the posterior cord behind, and the lateral cord on the lateral side of the artery. In the lower part of the axilla the cords split into the nerves for the upper limb. With the exception of the medial root of the median nerve, the branches of the three cords bear the same relationships to the third part of the axillary artery as the cords from which they spring bear to the second part, i.e. branches from the lateral cord are lateral, branches of the posterior cord are behind, and branches of the medial cord are medial to the artery.

Close to their exit from the intervertebral foramina the fifth and sixth cervical nerves receive grey rami communicantes from the middle cervical ganglion, and the seventh and eighth cervical similar rami from the inferior cervical ganglion of the sympathetic trunk (p. 1209). The first thoracic nerve receives a grey ramus from, and contributes a white ramus to, the first thoracic ganglion of the sympathetic trunk.

The branches of the brachial plexus.—The branches of the brachial plexus are usually subdivided into two groups, viz. those arising above the clavicle (*supraclavicular*) and those below that bone (*infraclavicular*).

THE SUPRACLAVICULAR BRANCHES

The supraclavicular branches may be grouped as follows: (a) those arising from the roots, and (b) those arising from the trunks of the plexus.

From the roots of the plexus.	1. To scaleni and longus cervicis	5, 6, 7, 8 C.
	2. To join phrenic nerve	5 C.
	3. Dorsal scapular nerve	5 C.
	4. Long thoracic nerve	5, 6, 7 C.
From the trunks of the plexus.	1. Nerve to subclavius	5, 6 C.
	2. Suprascapular nerve	5, 6 C.

The branches for the scaleni and longus cervicis muscles arise from the lower cervical nerves close to their points of exit from the intervertebral foramina.

On the scalenus anterior the phrenic nerve is joined by a branch from the fifth cervical nerve.

* The posterior division of the lower trunk is very much smaller than the others, and contains few fibres from the first thoracic nerve. It is frequently derived from the eighth cervical nerve before the trunk is formed.

The **dorsal scapular nerve** arises from the fifth cervical nerve, pierces the scalenus medius, passes on to the deep surface of the levator scapulæ, to which it occasionally gives a twig, and runs in company with the deep branch of the transverse cervical artery on the anterior surfaces of the rhomboids; it ends by supplying these muscles.

The **long thoracic nerve** (fig. 704) usually arises by three roots from the fifth, sixth, and seventh cervical nerves, but the root from the seventh nerve may be absent. The upper two roots pierce the scalenus medius obliquely, uniting either in the substance of the muscle or on its lateral surface, and the nerve so formed descends behind the brachial plexus and the first part of the axillary artery. Having crossed the upper border of the serratus anterior to gain its outer surface, it is soon joined by the root from C. 7, which emerges from the interval between the scalenus anterior and the scalenus medius at a lower level and descends on the lateral surface of the latter muscle. The nerve is continued downwards to the lower border of the serratus anterior, supplying, in its course, filaments to each of its digitations.

The **nerve to the subclavius** is a small nerve which arises from the point of junction of the fifth and sixth cervical nerves; it descends in front of the plexus and the third part of the subclavian artery, and is usually connected by a filament with the phrenic nerve. It then passes above the subclavian vein and reaches the subclavius muscle, which it supplies.

The **suprascapular nerve** (figs. 704, 970) is a large nerve which arises from the upper trunk of the brachial plexus. It runs laterally deep to the trapezius and the omohyoid, and enters the supraspinous fossa through the suprascapular notch, passing below the suprascapular ligament; it then runs deep to the supraspinatus, and curves round the lateral border of the spine of the scapula in company with the suprascapular artery to gain the infraspinous fossa. In the supraspinous fossa it gives two branches to the supraspinatus muscle, and articular filaments to the shoulder-joint and acromio-clavicular joint; and in the infraspinous fossa it gives two branches to the infraspinatus muscle, besides some filaments to the shoulder-joint and scapula.

THE INFRACLAVICULAR BRANCHES

The infraclavicular branches are derived from the three cords of the brachial plexus, but their fibres may be traced through the plexus to the spinal nerves from which they originate. They are as follows:

Lateral cord	Lateral pectoral	5, 6, 7 C.
	Musculocutaneous	5, 6, 7 C.
	Lateral root of median	6, 7 C.
Medial cord	Medial pectoral	
	Medial cutaneous of forearm	
	Medial cutaneous of arm	8 C., 1 T.
	Medial root of median	
	Ulnar*	(7), 8 C., 1 T.
Posterior cord	Upper subscapular	5, 6 C.
	Lower subscapular	5, 6 C.
	Axillary (Circumflex humeral)	5, 6 C.
	Thoracodorsal	6, 7, 8 C.
	Radial	5, 6, 7, 8 C., 1 T.

The **pectoral nerves** (fig. 968) supply the pectoralis major and pectoralis minor.

The **lateral pectoral nerve**, the larger of the two, may arise by two roots from the anterior divisions of the upper and middle trunks, or by a single root from the point where these divisions unite to form the lateral cord of the plexus; it receives its fibres from the fifth, sixth, and seventh cervical nerves. It crosses the axillary artery and vein anteriorly, pierces the clavipectoral fascia, and is distributed to the deep surface of the pectoralis major. It sends a filament to join the medial pectoral nerve and forms with it a loop in front of the first part of the axillary artery (fig. 968); through this loop the lateral pectoral nerve distributes some fibres to the pectoralis minor.

* See footnote on p. 1162.

The *medial pectoral nerve* receives its fibres from the eighth cervical and first thoracic nerves, and arises from the medial cord of the plexus while that cord is still posterior to the axillary artery. It curves forwards between the axillary artery and vein, and unites in front of the artery with a filament from the lateral pectoral nerve. It then enters the deep surface of the pectoralis minor and supplies that muscle. Two or three branches pierce the pectoralis minor, and others may pass round its inferior border, to end in the pectoralis major.

The **subscapular nerves**, two in number, spring from the posterior cord of the plexus, and through it from the fifth and sixth cervical nerves.

The *upper subscapular nerve*, the smaller, enters the upper part of the subscapularis, and is frequently represented by two branches.

The *lower subscapular nerve* supplies the lower part of the subscapularis, and ends in the *teres major*; the latter muscle is sometimes supplied by a separate branch.

The **thoracodorsal nerve**, a branch of the posterior cord of the plexus, derives its fibres from the sixth, seventh and eighth cervical nerves; it arises between the upper and lower subscapular nerves and then accompanies the subscapular artery along the posterior wall of the axilla and supplies the *latissimus dorsi*, in which it may be traced as far as the lower border of the muscle.

The **axillary (circumflex humeral) nerve** (fig. 970) arises from the posterior cord of the brachial plexus, its fibres being derived from the fifth and sixth cervical nerves. It lies at first on the lateral side of the radial nerve and is placed behind the axillary artery, and in front of the subscapularis. At the lower border of that muscle it winds backwards in close relation to the lowest part of the articular capsule of the shoulder-joint, and, in company with the posterior circumflex humeral vessels, passes through a quadrangular space bounded above by the subscapularis, in front, and the *teres minor*, behind, below by the *teres major*, medially by the long head of the triceps and laterally by the surgical neck of the humerus. The nerve ends by dividing into an anterior and a posterior branch.

The *anterior branch*, accompanied by the posterior circumflex humeral vessels, winds round the surgical neck of the humerus, deep to the deltoid, as far as the anterior border of the muscle, supplying it, and giving a few small cutaneous branches which pierce the muscle and ramify in the skin covering its lower part.

The *posterior branch* supplies the *teres minor* and the posterior part of the deltoid; upon the branch to the *teres minor* an oval enlargement (*pseudoganglion*) usually exists. The posterior branch pierces the deep fascia at the lower part of the posterior border of the deltoid and is continued as the *upper lateral cutaneous nerve of the arm*, which supplies the skin over the lower part of the deltoid and the skin covering the upper part of the long head of the triceps (figs. 964, 965).

The trunk of the axillary nerve gives an articular filament which enters the shoulder-joint below the subscapularis.

The **musculocutaneous nerve** (fig. 968) arises from the lateral cord of the brachial plexus, opposite the lower border of the pectoralis minor, its fibres being derived from the fifth, sixth, and seventh cervical nerves. It pierces the coracobrachialis and runs downwards and laterally between the biceps and the brachialis to reach the lateral side of the arm; a little below the elbow it pierces the deep fascia on the lateral side of the tendon of the biceps and is continued into the forearm as the *lateral antebrachial cutaneous nerve*. A line drawn downwards and laterally from the lateral side of the third part of the axillary artery, across the elevations produced by the coracobrachialis and the biceps, to the lateral side of the biceps tendon of insertion indicates the position of the musculocutaneous nerve relative to the surface. In its course through the arm it supplies the coracobrachialis, both heads of the biceps and the greater part of the brachialis. The branch to the coracobrachialis leaves the musculocutaneous before that nerve enters the muscle; it receives its fibres from the seventh cervical nerve, and in some instances arises directly from the lateral cord of the brachial plexus. The branches to the biceps and brachialis leave the musculocutaneous nerve after it has pierced the coracobrachialis; that supplying the brachialis gives a filament to the elbow-joint. The nerve also sends a small branch to the humerus; this branch enters the bone with the nutrient artery.

The *lateral cutaneous nerve of the forearm* (fig. 964) passes deep to the cephalic vein, and descends along the radial border of the forearm to the wrist. It supplies the skin over the lateral half of the anterior surface of the forearm and distributes branches which turn round the radial border of the forearm to communicate with

the posterior cutaneous nerve of the forearm and the terminal branch of the radial nerve. At the wrist-joint it is placed in front of the radial artery, and some filaments, piercing the deep fascia, accompany that vessel to the dorsal surface of the carpus. The nerve then passes downwards to the base of the thenar eminence, where it ends

FIG. 964.—The cutaneous nerves of the right upper limb. Anterior surface.

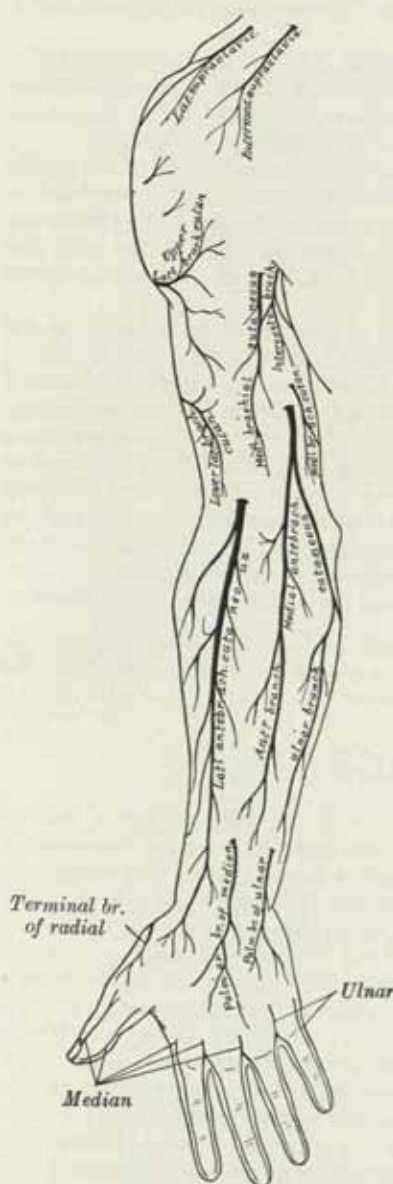
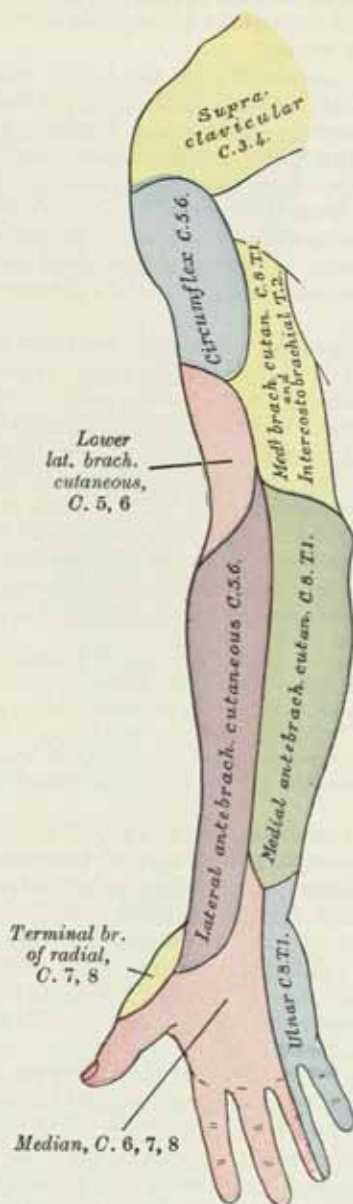


FIG. 965.—A diagram showing the distribution of the cutaneous nerves of the right upper limb. Anterior surface.



in cutaneous filaments. It communicates with the terminal branch of the radial nerve, and with the palmar cutaneous branch of the median nerve.

The musculocutaneous nerve presents frequent irregularities. It may run behind the coracobrachialis or it may adhere for some distance to the median nerve and then pass behind the biceps instead of through the coracobrachialis. Some of the fibres of the median nerve may run for some distance in the musculocutaneous nerve and then leave it to join their proper trunk; less frequently the reverse is

the case, and the median nerve sends a branch to join the musculocutaneous nerve. Occasionally it gives a filament to the pronator teres and, sometimes, it may replace the branches of the radial nerve to the dorsal surface of the thumb.

The **medial cutaneous nerve of the forearm** (fig. 968) arises from the medial cord of the brachial plexus. It derives its fibres from the eighth cervical and first thoracic nerves, and at its commencement is placed between the axillary artery and vein. Near the axilla it supplies a filament which pierces the fascia and is distributed to the skin covering the biceps, almost as far as the elbow. The nerve then runs down the arm on the medial side of the brachial artery, pierces the deep fascia with the basilic vein about the middle of the arm, and divides into an anterior and a posterior branch.

The *anterior branch*, the larger, passes usually in front of, but occasionally behind, the median cubital vein. It then descends on the front of the medial side of the forearm, distributing filaments to the skin as far as the wrist, and communicating with the palmar cutaneous branch of the ulnar nerve (fig. 964).

The *posterior branch* passes obliquely downwards on the medial side of the basilic vein, in front of the medial epicondyle of the humerus, winds round to the back of the forearm, and descends on its medial side as far as the wrist, distributing filaments to the skin. It communicates with the medial cutaneous nerve of the arm, the posterior cutaneous nerve of the forearm, and the dorsal branch of the ulnar nerve (fig. 966).

The **medial cutaneous nerve of the arm** is distributed to the skin on the medial side of the arm (fig. 964). It is the smallest branch of the brachial plexus, and, arising from the medial cord, receives its fibres from the eighth cervical and first thoracic nerves. It passes through the axilla and crosses in front of, or behind, the axillary vein. It then runs on the medial side of this vein, and communicates with the intercostobrachial nerve. It descends along the medial side of the brachial artery and basilic vein to the middle of the upper arm, where it pierces the deep fascia, and is distributed to the skin of the medial side of the lower one-third of the arm, extending on to its anterior and posterior aspects; some filaments reach the skin in front of the medial epicondyle and others over the olecranon. It communicates with the posterior branch of the medial cutaneous nerve of the forearm.

In some subjects the medial brachial cutaneous and intercostobrachial nerves are connected by two or three filaments, which form a plexus in the axilla. In others the intercostobrachial nerve is large and may be reinforced by a part of the lateral cutaneous branch of the third intercostal nerve; it then takes the place of the medial brachial cutaneous nerve, receiving from the brachial plexus a communicating filament which represents the latter nerve; occasionally this filament is wanting.

The **median nerve** (fig. 968) arises by two roots, one from the lateral and the other from the medial cord of the brachial plexus; these embrace the lower part of the axillary artery, uniting either in front or on the lateral side of that vessel. Its fibres are derived from the (fifth), sixth, seventh, and eighth cervical and first thoracic nerves. In most cases some of the fibres derived from C. 7 leave the lateral head of the median in the lower part of the axilla and pass downwards and medially, behind the medial head, to join the ulnar nerve (fig. 963). As the median nerve descends through the arm, it lies at first lateral to the brachial artery; about the level of the insertion of the coracobrachialis it crosses in front of, occasionally behind, the artery, and then descends on its medial side to the bend of the elbow, where it is situated behind the bicipital aponeurosis, and is separated from the elbow-joint by the brachialis. Its intimate relation to the brachial artery renders its course easy to indicate in the living subject. It enters the forearm between the two heads of the pronator teres; here it crosses the ulnar artery, but is separated from it by the deep head of the pronator teres (fig. 968). It passes behind the tendinous bridge which connects the humero-ulnar to the radial head of the flexor digitorum superficialis and descends through the forearm under cover of, and adherent to, that muscle, lying on the flexor digitorum profundus. In this part of its course, it occasionally gives off a communicating branch to the ulnar nerve. About 5 cm. above the flexor retinaculum it emerges from behind the oblique lateral border of the radial head of the flexor digitorum superficialis and becomes more superficial. It now lies between the tendons of the flexor digitorum superficialis and the flexor carpi radialis, behind, but rather to the lateral side of, the tendon of the palmaris longus.

It then passes behind the flexor retinaculum and gains the palm of the hand. In its course through the forearm it is closely accompanied by the median artery, a branch of the anterior interosseous artery. This part of the nerve can be represented on the surface by a line drawn downwards from the medial side of the termination of the

FIG. 966.—The cutaneous nerves of the right upper limb. Posterior surface.

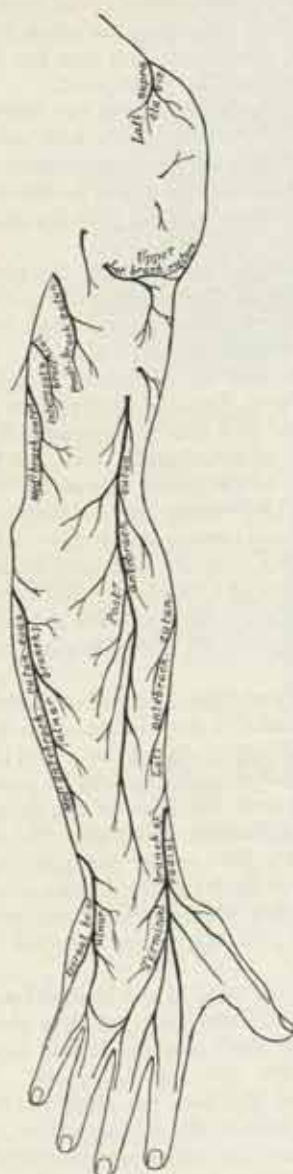
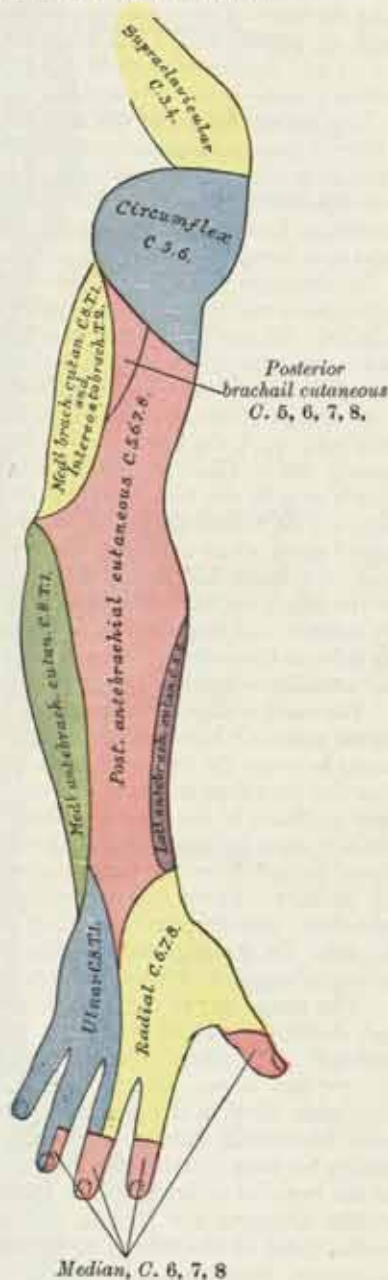


FIG. 967.—A diagram showing the distribution of the cutaneous nerves of the right upper limb. Posterior surface.



brachial artery, approximately in the middle line of the limb. Just above the wrist it projects laterally from under cover of the palmaris longus tendon and, in this situation, it lies a little to the medial side of the tendon of the flexor carpi radialis.

Branches.—With the exception of the nerve to the pronator teres, which derives its fibres from the sixth cervical nerve and usually arises above the elbow-joint, the

median nerve gives no branches in the arm. As it passes in front of the elbow, it supplies one or two twigs to the joint.

In the forearm its branches are: muscular, anterior interosseous, and palmar.

The *muscular branches* are derived from the nerve near the elbow and supply all the superficial flexor muscles on the front of the forearm, except the flexor carpi ulnaris.

The *anterior interosseous nerve* arises from the median as it passes between the two heads of the pronator teres, and accompanies the anterior interosseous artery along the front of the interosseous membrane of the forearm in the interval between the flexor pollicis longus and flexor digitorum profundus, supplying the whole of the former and the lateral half of the latter muscle; it sends branches into the deep surface of the pronator quadratus, and ends by supplying the wrist-joint.

The *palmar branch* of the median nerve arises at the lower part of the forearm. It pierces the deep fascia above the flexor retinaculum, and divides into a lateral and a medial branch; the lateral branch supplies the skin over the thenar eminence, and communicates with the anterior branch of the lateral cutaneous nerve of the forearm; the medial branch supplies the skin of the palm, and communicates with the palmar cutaneous branch of the ulnar nerve.

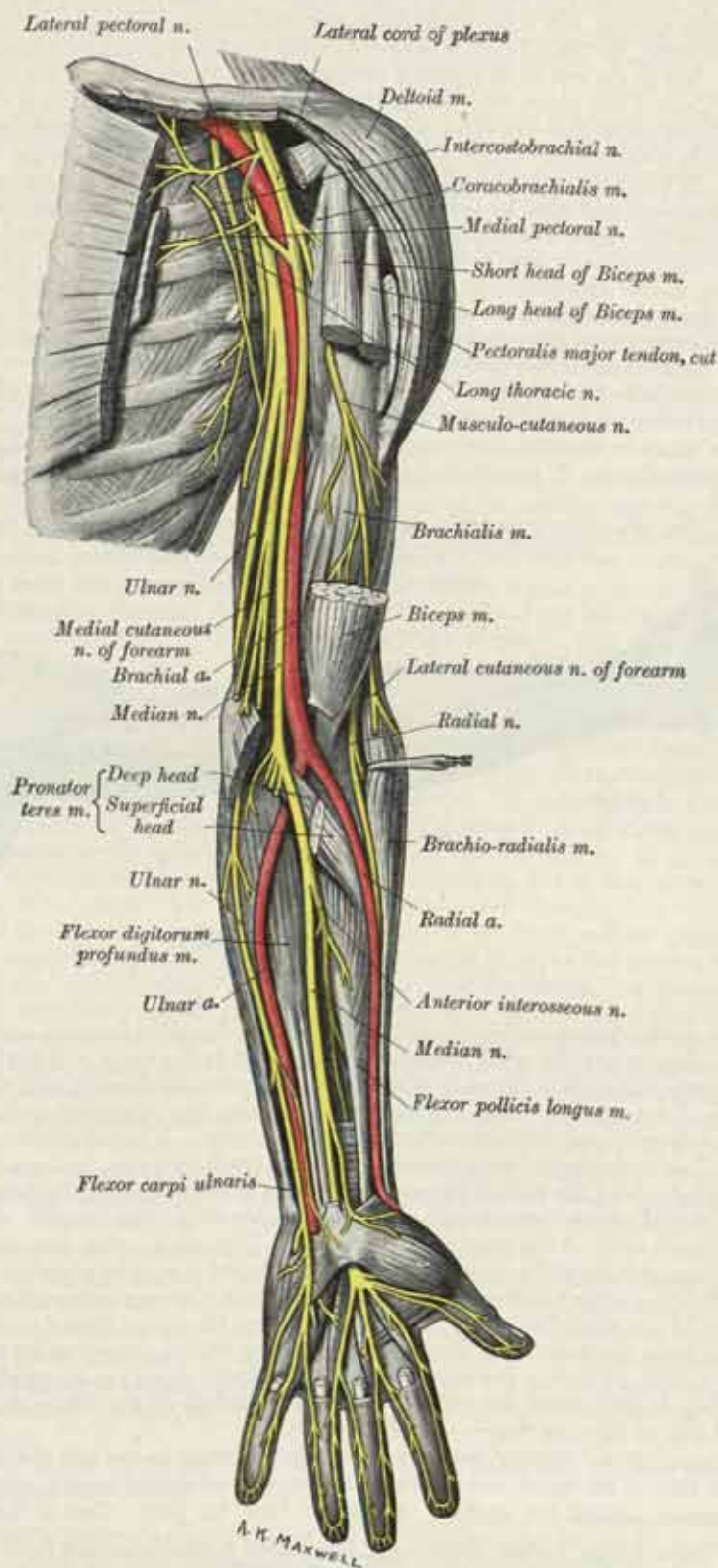
In the palm of the hand the median nerve is covered by the skin, the palmar aponeurosis and the superficial palmar arch, and rests on the tendons of the flexor muscles. Immediately after emerging from behind the flexor retinaculum it becomes enlarged and flattened, and splits into a lateral and a medial portion. The *lateral* portion of the nerve supplies a short, stout branch to the following muscles of the thenar eminence, viz. the abductor pollicis brevis, the opponens pollicis and, usually (p. 647), the flexor pollicis brevis, and then divides into three *palmar digital nerves*; two of these supply the sides and the joints of the thumb, while the third gives a twig to the first lumbrical and is distributed to the radial side of the index finger. The *medial* portion of the nerve divides into two *palmar digital nerves*. The first of these gives a twig to the second lumbrical and runs towards the cleft between the index and middle fingers, where it divides into two collateral branches for the adjoining sides of these digits. The second runs towards the cleft between the middle and ring fingers, and splits into two collateral branches for the adjoining sides of these digits; it receives a communicating branch from the ulnar nerve, and sometimes sends a twig to the third lumbrical.

The palmar digital nerves are at first deep to the superficial palmar arch and the digital vessels which arise from it. As they pass distally and divide, each artery passes between the collateral branches of the corresponding digital nerve and thereafter lies on a deeper plane. In the fingers the collateral digital nerves lie immediately in front of the corresponding arteries. Opposite the base of the proximal phalanx, each collateral digital nerve gives off a dorsal branch, which joins the dorsal digital branch from the radial nerve, and supplies the skin on the dorsal surface of the phalanx. At the end of the digit, each collateral digital nerve divides into two branches; one supplies the pulp of the finger, the other ramifies around and beneath the nail. On the fingers the collateral digital nerves give articular twigs to the metacarpophalangeal and interphalangeal joints.

The **ulnar nerve** (fig. 968) arises from the medial cord of the brachial plexus, and derives its fibres from the seventh and eighth cervical and first thoracic nerves.* The fibres from C. 7 run in the lateral cord and the lateral head of the median nerve, which they leave in the lower part of the axilla. They then pass deep to the medial head of the median and join the ulnar nerve. It runs downwards through the axilla on the medial side of the axillary artery, intervening between it and the axillary vein, and continues downwards on the medial side of the brachial artery as far as the middle of the upper arm. Here it pierces the medial intermuscular septum, and inclines medially, as it descends in front of the medial head of the triceps to the interval between the medial epicondyle and the olecranon, accompanied by the superior ulnar collateral artery. At the elbow it lies in a groove on the back of the medial epicondyle, and as it enters the forearm parts of the two heads of the flexor carpi ulnaris, it lies on the posterior and oblique parts of the ulnar collateral (medial) ligament of the elbow-joint. It descends along

* E. A. Linell, *J. Anat.*, 55, 1920, found a considerable bundle of seventh cervical nerve-fibres running from the lateral root of the median nerve to the ulnar nerve in 57 per cent. of subjects.

FIG. 968.—The nerves of the left upper limb.



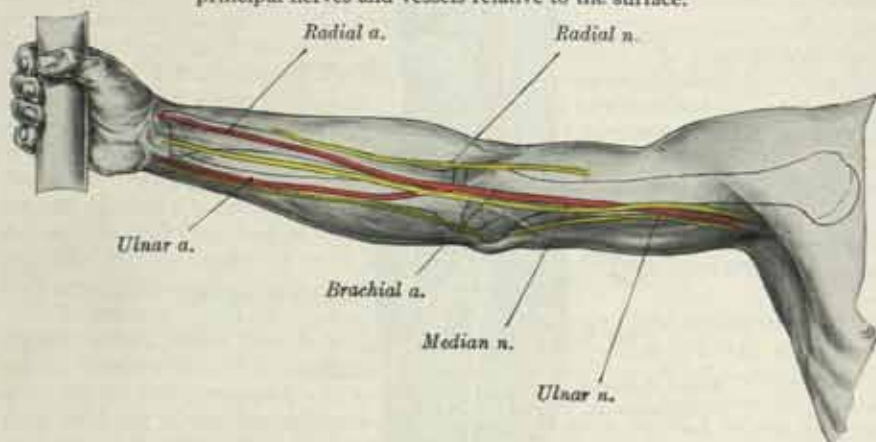
the medial side of the forearm, lying upon the flexor digitorum profundus; its upper half is covered by the flexor carpi ulnaris; its lower half lies on the lateral side of this muscle, and is covered by the skin and fasciæ. In the upper one-third of the forearm, the ulnar nerve is separated from the ulnar artery by a considerable interval, but in the rest of its extent it lies close to the medial side of the vessel (fig. 968). About 5 cm. above the wrist it gives off a dorsal branch, and it is then continued downwards into the hand, passing in front of the flexor retinaculum on the lateral side of the pisiform bone and lying medial to and somewhat behind the ulnar artery. In company with the artery the nerve passes behind the superficial part of the retinaculum and ends by dividing into a superficial and a deep terminal branch. Its relationship to the brachial artery in the arm and to the medial epicondyle at the elbow render the nerve easy to map out in the upper part of its course; a line drawn from the medial epicondyle to the lateral edge of the pisiform bone represents its course through the forearm.

The branches of the ulnar nerve are: articular to the elbow-joint, muscular, palmar cutaneous, dorsal, and superficial terminal and deep terminal.

The *articular branches* to the elbow-joint are several small filaments which arise from the nerve as it lies between the medial epicondyle and olecranon.

The *muscular branches*, two in number, arise near the elbow; one supplies the flexor carpi ulnaris; * the other, the medial half of the flexor digitorum profundus.

FIG. 969.—The front of the right upper limb, showing the position of the principal nerves and vessels relative to the surface.



The *palmar cutaneous branch* arises about the middle of the forearm, and descends on the ulnar artery (fig. 968), giving some filaments to the vessel. It perforates the deep fascia and ends in the skin of the palm, after communicating with the palmar branch of the median nerve. It sometimes supplies the palmaris brevis.

The *dorsal branch* arises about 5 cm. above the wrist; it passes distally and backwards deep to the flexor carpi ulnaris, perforates the deep fascia, and, running along the medial side of the back of the wrist and hand, divides into two, frequently three, dorsal digital nerves: one supplies the medial side of the little finger; the second the adjacent sides of the little and ring fingers. The third, when present, supplies the adjoining sides of the ring and middle fingers, but it may be replaced, wholly or partially, by a branch of the radial nerve, with which it always communicates on the dorsum of the hand (fig. 966). On the little finger the dorsal digital nerves extend only as far as the base of the distal phalanx, and on the ring finger as far as the base of the middle phalanx; the more distal parts of these digits are supplied by dorsal branches derived from the collateral digital branches of the ulnar and—on the lateral side of the ring finger—median nerves.

The *superficial terminal branch* supplies the palmaris brevis and the skin on the medial side of the hand, and divides into two palmar digital nerves, which can be compressed against the hook of the hamate bone (p. 386). One of these palmar

* Wilfred Harris, *J. Anat. Physiol.*, 38, 1904, found a branch running from the seventh cervical nerve to the ulnar nerve in 86 per cent. of subjects, and believed, on clinical grounds, that the fibres of this branch were mainly motor to the flexor carpi ulnaris.

digital nerves supplies the medial side of the little finger ; the other sends a twig to join the median nerve and then divides into two collateral branches for the adjoining sides of the little and ring fingers (fig. 968). The collateral branches are distributed to the fingers in the same manner as those of the median nerve. The *deep terminal branch*, accompanied by the deep branch of the ulnar artery, passes between the abductor digiti minimi and flexor digiti minimi ; it then perforates the opponens digiti minimi and follows the course of the deep palmar arch behind the flexor tendons. At its origin it supplies the three short muscles of the little finger. As it crosses the hand, it gives branches to the interossei and to the third and fourth lumbricals ; it ends by supplying the adductor pollicis, the first palmar interosseous muscle and, in most cases (p. 647), the flexor pollicis brevis. It also sends articular filaments to the wrist-joint.

It has been pointed out that the medial part of the flexor digitorum profundus is supplied by the ulnar nerve ; the third and fourth lumbricals, which are connected with the tendons of this part of the muscle, are supplied by the same nerve. In like manner the lateral part of the flexor digitorum profundus and the first and second lumbricals are supplied by the median nerve. The third lumbrical frequently receives an additional twig from the median nerve.

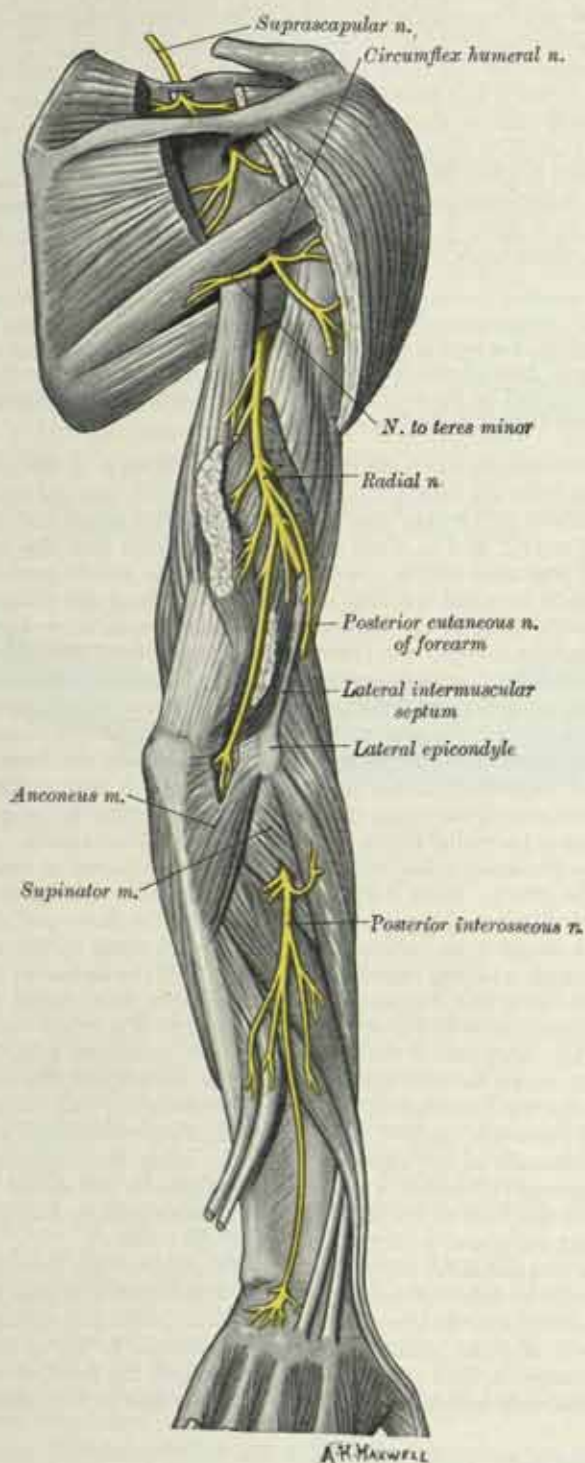
The **radial nerve** (fig. 970), which is the largest branch of the brachial plexus, derives its fibres from the fifth, sixth, seventh, and eighth cervical and first thoracic nerves. It descends behind the third part of the axillary artery and the upper part of the brachial artery, and in front of the subscapularis and the tendons of the latissimus dorsi and teres major. Accompanied by the arteria profunda brachii it inclines backwards between the long and medial heads of the triceps, and passes obliquely across the back of the humerus in a shallow groove, and under cover of the lateral head of the triceps. On reaching the lateral side of the humerus it pierces the lateral intermuscular septum and enters the anterior compartment of the arm. It then descends, lying deeply in the intermuscular furrow which is bounded on the medial side by the brachialis and on the lateral side by the brachioradialis, above, and the extensor carpi radialis longus, below. On reaching the front of the lateral epicondyle it gives off the posterior interosseous nerve. It then descends along the front of the lateral side of the upper two-thirds of the forearm, lying at first upon the supinator, lateral to the radial artery, and behind the brachioradialis. In the middle one-third of the forearm, it lies behind the same muscle, but is now close to the lateral side of the artery. Here it lies first on the pronator teres, next on the radial head of the flexor digitorum superficialis, and then on the flexor pollicis longus. It quits the artery about 7 cm. above the wrist, passes deep to the tendon of the brachioradialis, and, winding round the lateral side of the radius as it descends, it pierces the deep fascia and divides into five, sometimes four, dorsal digital nerves, which are distributed as follows : the first supplies the skin of the radial side of the thumb and the adjoining part of the thenar eminence, communicating with branches of the lateral cutaneous nerve of the forearm ; the second supplies the medial side of the thumb ; the third, the lateral side of the index finger ; the fourth, the adjoining sides of the index and middle fingers ; the fifth communicates with a filament from the dorsal branch of the ulnar nerve, and supplies the adjoining sides of the middle and ring fingers,* but it is frequently replaced by the dorsal branch of the ulnar nerve. On the back of the hand the radial nerve usually communicates with the posterior and the lateral cutaneous nerves of the forearm.

In the arm the radial nerve corresponds to a line drawn from the commencement of the brachial artery and carried downwards and laterally across the elevations produced by the long and the lateral heads of the triceps to the junction of the upper and middle thirds of a line joining the lateral epicondyle to the deltoid tuberosity. The line of the nerve is then continued downwards on the front of the arm to the level of the lateral epicondyle, where it lies 1 cm. or less to the lateral side of the biceps tendon.

The branches of the radial nerve are : muscular, cutaneous, articular and the posterior interosseous nerve.

* According to Hutchison, the digital nerve to the thumb reaches only as far as the root of the nail ; the one to the forefinger as far as the middle of the middle phalanx ; and those to the middle and ring fingers not farther than the proximal interphalangeal joints.—*London Hospital Gazette*, vol. iii, p. 319.

FIG. 970.—The right suprascapular, circumflex humeral, and radial nerves.



The *muscular branches* supply the triceps, anconeus, brachioradialis, extensor carpi radialis longus and brachialis, and are grouped as medial, posterior and lateral. The medial muscular branches arise from the radial nerve on the medial side of the arm and supply the medial and long heads of the triceps; the branch to the

medial head is a long, slender filament, which lies close to the ulnar nerve as far as the lower one-third of the arm, and is therefore frequently named the *ulnar collateral nerve*.

The posterior muscular branch, of large size, arises from the nerve as it lies in the groove. It divides into filaments which supply the medial and lateral heads of the triceps and the anconeus. The branch for the latter muscle is a long nerve which descends in the substance of the medial head of the triceps, and gives numerous branches to it. It is accompanied by a branch of the *arteria profunda brachii*, and passes behind the elbow-joint to end in the anconeus.

The lateral muscular branches arise from the nerve as it lies in front of the lateral intermuscular septum; they supply the lateral part of the brachialis, the brachioradialis, and the extensor carpi radialis longus.

The *cutaneous branches* are the posterior cutaneous and the lower lateral cutaneous nerves of the arm and the posterior cutaneous nerve of the forearm.

The *posterior cutaneous nerve of the arm*, of small size, arises in the axilla and passes to the medial side of the arm to supply the skin on its dorsal surface nearly as far as the olecranon. It crosses posterior to, and communicates with, the intercostobrachial nerve.

The *lower lateral cutaneous nerve of the arm* perforates the lateral head of the triceps just below the insertion of the deltoid muscle. It then passes to the front of the elbow, lying close to the cephalic vein, and supplies the skin of the lateral part of the lower half of the arm (fig. 964). The *posterior cutaneous nerve of the forearm* arises in common with the preceding branch. After perforating the lateral head of the triceps, it descends along the lateral side of the arm, and then along the back of the forearm to the wrist, supplying the skin in its course, and joining, near its termination, with dorsal branches of the lateral cutaneous nerve of the forearm (fig. 964).

The *articular branches* are distributed to the elbow-joint.

The *posterior interosseous nerve* (fig. 970) winds to the back of the forearm round the lateral side of the radius between the two planes of fibres of the supinator. It gives a branch to the extensor carpi radialis brevis, and another to the supinator before it enters the latter muscle, and as it traverses its substance it supplies additional branches to it. The branch to the extensor carpi radialis brevis may spring from the radial nerve itself, just beyond the origin of the posterior interosseous nerve. As soon as it escapes from the supinator on the back of the forearm the posterior interosseous nerve gives off three short branches—to the extensor digitorum, extensor digiti minimi and extensor carpi ulnaris—and two long branches—a medial to the extensor pollicis longus and the extensor indicis, and a lateral, which supplies the abductor pollicis longus and ends in the extensor pollicis brevis. The nerve lies at first between the superficial and the deep muscles of the back of the forearm, but, at the lower border of the extensor pollicis brevis, it passes deep to the extensor pollicis longus and, diminished to a fine thread, runs down on the dorsal aspect of the interosseous membrane of the forearm. Finally it reaches the back of the carpus, where it presents a flattened and somewhat expanded termination from which filaments are distributed to the ligaments and articulations of the carpus (fig. 970).

The *dermatomes* (p. 1192) of the upper limb are described on p. 1193.

Applied Anatomy.—The brachial plexus may be injured by falls from a height on to the side of the head and shoulder, whereby the nerves of the plexus are violently stretched; the upper trunk of the plexus sustains the greatest amount of injury, and the subsequent paralysis may be confined to the muscles supplied by the fifth nerve, viz. the deltoid, biceps, brachialis and brachioradialis, with sometimes the supraspinatus, infraspinatus and supinator. The position of the limb, under such conditions, is characteristic: the arm hangs by the side and is rotated medially; the forearm is extended and pronated. The arm cannot be raised from the side; all power of flexion of the elbow is lost, as is also supination of the forearm. This is known as Erb's paralysis, and a very similar condition is occasionally met with in new-born children, either from injury to the upper trunk from the pressure of the forceps used in effecting delivery, or from traction of the head in breech presentations. A second variety of partial palsy of the brachial plexus is known as Klumpke's paralysis. In this it is the eighth cervical and first thoracic nerves that are injured, either before or after they have joined to form the lower trunk. The subsequent paralysis affects, principally, the intrinsic muscles of the hand and the flexors of the wrist and fingers.

The brachial plexus may also be injured by direct violence or a gunshot wound, by violent traction on the arm, or by effort at reducing a dislocation of the shoulder-joint; and the amount of paralysis will depend upon the amount of injury to the constituent nerves. When the entire plexus is involved, the whole of the upper extremity will be paralysed and anæsthetic. In some cases the injury appears to be rather a tearing away of the roots of the nerves from the spinal medulla than a rupture of the nerves themselves, and where this involves the first thoracic nerve the pupil on the same side may be constricted, on account of damage to the preganglionic fibres destined for the supply of the dilator muscle. The brachial plexus in the axilla is often damaged from the pressure of a crutch, producing the condition known as 'crutch paralysis.' In these cases the radial is the nerve most frequently implicated; the ulnar nerve suffers next in frequency. The median and radial nerves often suffer from 'sleep palsies,' paralysis from pressure coming on while the patient is profoundly asleep under the influence of alcohol or some narcotic.

Paralysis of the long thoracic nerve throws the serratus anterior muscle out of action, and may occur in porters who have to carry heavy weights on the shoulder, for the nerve is exposed to injury as it lies in the posterior triangle of the neck. The inferior angle of the scapula is drawn towards the median plane, by the unopposed action of the rhomboids and levator scapulæ, and tends to project backwards (winging of the scapula) when the arm is held horizontally forwards or when forward pushing movements are attempted against resistance. The arm cannot be raised above the horizontal unless the inferior angle of the scapula is pushed laterally and forwards for the patient.

The *axillary (circumflex humeral) nerve*, on account of its course round the surgical neck of the humerus, is liable to be injured in fractures of this part of the bone, and in dislocations of the shoulder-joint; paralysis of the deltoid, and anæsthesia of the skin over the lower part of that muscle, result. Paralysis of the deltoid renders effective abduction of the arm impossible. The associated paralysis of the *teres minor* is not easily demonstrated.

The *median nerve* is liable to injury in wounds of the forearm. When it is completely divided above the origin of its muscular and anterior interosseous branches, there is loss of flexion of the second phalanges of all the fingers, and of the terminal phalanges of the index and middle fingers. Flexion of the terminal phalanges of the ring and little fingers is effected by that portion of the *flexor digitorum profundus* which is supplied by the ulnar nerve. There is power to flex the proximal phalanges through the interossei. The thumb cannot be opposed or abducted nor can it be flexed at the interphalangeal joint (see p. 1162), and it is maintained in a position of extension and adduction. There is loss in the power of pronating the forearm; the *brachioradialis* has the power of bringing the forearm into a position of mid-pronation, but beyond this no further pronation can be effected. The wrist can be flexed by the *flexor carpi ulnaris*, but flexion is combined with adduction of the hand. There is loss or impairment of sensation on the palmar surfaces of the thumb, index, middle, and radial half of the ring fingers, and on the dorsal surfaces of the same fingers over the last two phalanges; except in the thumb, where the loss of sensation is limited to the back of the distal phalanx. Owing to the paralysis of the short muscles of the thumb, an 'ape-like' hand is produced. More commonly, however, the nerve is injured just above the *flexor retinaculum*, when the power of flexion of the fingers and pronation of the forearm remains intact, unless the flexor tendons are also divided.

The *ulnar nerve* is also liable to be injured in wounds of the forearm, such injury leading to impaired power of ulnar flexion, and, upon an attempt being made to flex the wrist, the hand is drawn to the radial side by the *flexor carpi radialis*; there is inability to spread out the fingers owing to paralysis of the dorsal interossei, and for the same reason the fingers, especially the ring and little fingers, cannot be flexed at the metacarpophalangeal joints or extended at the interphalangeal joints, and the hand assumes a claw shape from the action of the opposing muscles; there is loss of power of flexion in the little and ring fingers; and there is inability to adduct the thumb. The muscles of the *hypotenar eminence* become wasted. Sensation is lost, or impaired, in the skin supplied by the nerve.

The *radial nerve* also is frequently injured. In consequence of its close relationship to the humerus, it is often torn or injured in fractures of this bone, or subsequently involved during the repair of the fracture. It is also liable to be contused against the bone by kicks or blows, or to be divided in wounds of the arm. When paralysed, the hand is flexed at the wrist and lies flaccid. This is known as *wrist-drop*. The fingers are also flexed, and when an attempt is made to extend them, the last two phalanges only will be extended, through the action of the lumbrical and interosseous muscles; the first phalanges remain flexed. Extension of the wrist is impossible. Supination is completely lost when the forearm is extended on the arm, but is possible to a certain extent if the forearm be flexed so as to allow of the action of the biceps. The power of extension of the forearm is lost on account of paralysis of the triceps, if the injury to the nerve has taken place near its origin. As the radial nerve has only a very small area of

exclusive supply, the extent of the anaesthesia associated with severe injuries to the nerve is surprisingly small and is confined to a limited region on the lateral part of the dorsum of the hand.

THE VENTRAL RAMI OF THE THORACIC NERVES

The **ventral rami of the thoracic nerves** (fig. 971) are twelve in number on each side. Eleven of them are situated between the ribs, and are therefore termed *intercostal*; the twelfth lies below the last rib and is usually termed the *subcostal nerve*. Each nerve is connected with the adjoining ganglion of the sympathetic trunk by a grey and a white ramus communicans; occasionally these two rami are enclosed in a common sheath, but, as a rule, they remain separate and the grey ramus joins the nerve proximal to the point at which the white ramus leaves it. The intercostal nerves are distributed chiefly to the parietes of the thorax and abdomen. The first two nerves supply fibres to the upper limb in addition to their thoracic branches; the next four are limited in their distribution to the parietes of the thorax; the lower five supply the parietes of the thorax and abdomen; the lower seven supply fibres to the diaphragm; the subcostal nerve is distributed to the abdominal wall and the skin of the buttock. Communicating branches link the intercostal nerves to one another in the posterior parts of the intercostal spaces and, in addition, the lower five communicate freely as they traverse the abdominal wall.*

The upper thoracic nerves.—The ventral ramus of the first thoracic nerve divides into a large and a small branch. The large branch ascends in front of the neck of the first rib on the lateral side of the superior intercostal artery, and enters the brachial plexus (p. 1155). The small branch is the *first intercostal nerve*; it runs along the first intercostal space, and ends on the front of the chest as the first anterior cutaneous branch of the thorax. Not infrequently this anterior cutaneous branch, which is always small, may be wanting. The first intercostal nerve as a rule gives off no lateral cutaneous branch; but sometimes it sends a small branch to communicate with the intercostobrachial. The first thoracic nerve frequently receives a connecting twig from the second nerve; this twig ascends in front of the neck of the second rib.

The ventral rami of the second, third, fourth, fifth, and sixth thoracic nerves pass forwards (fig. 972) in the intercostal spaces below the intercostal vessels. At the back of the chest they lie between the pleura and the posterior intercostal membranes, but in most of their course they run between the internal intercostal muscles and the intercostales intimi (p. 583). Where the latter muscles are absent, the nerves lie in contact with the parietal pleura. Near the sternum, they cross in front of the internal thoracic artery and transversus thoracis muscle, pierce the internal intercostals, the external intercostal membranes, and the pectoralis major, and their terminal branches form the *anterior cutaneous nerves of the thorax*; they supply the skin of the front of the thorax; the anterior cutaneous branch of the second nerve may be connected to the medial supraclavicular nerves of the cervical plexus. Twigs from the anterior cutaneous branch of the sixth nerve supply the skin of the abdominal wall in the upper part of the infrasternal angle (fig. 987).

Branches.—Numerous slender muscular filaments supply the intercostal muscles, the serratus posterior superior, and the transversus thoracis. At the front of the thorax some of these branches cross the costal cartilages from one intercostal space to another.

Each intercostal nerve, except the first, gives off a *collateral branch* † and a *lateral cutaneous branch* before it reaches the angle of the rib. The collateral branch follows the lower border of the space in the same intermuscular interval as the main trunk, which it may, or may not, rejoin before it is distributed as an additional anterior cutaneous nerve. The lateral cutaneous branch accompanies the main trunk for a time and then pierces the intercostal muscles obliquely. With the exception of the lateral cutaneous branch of the second intercostal nerve, each divides into anterior and posterior branches, which subsequently pierce the serratus anterior muscle. The *anterior branches* run forwards over the border of the pectoralis major and supply twigs to the overlying skin; those of the fifth and sixth nerves supply twigs to the upper digitations of the external oblique muscle. The *posterior branches* run backwards, and supply the skin over the scapula and latissimus dorsi.

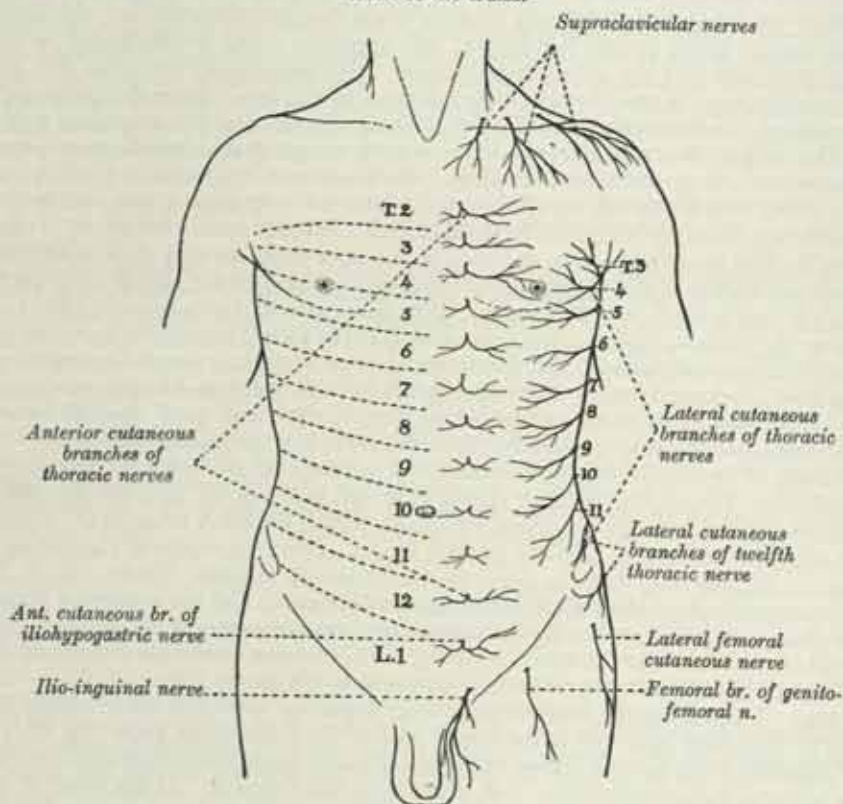
* F. Davies, R. J. Gladstone and E. P. Stibbe, *J. Anat.*, 66, 1932.

† F. Davies, *J. Anat.*, 70, 1935.

The lateral cutaneous branch of the second intercostal nerve is named the *intercostobrachial nerve* (fig. 968). It crosses the axilla to gain the medial side of the arm, and joins with a filament from the medial cutaneous nerve of the arm. It then pierces the deep fascia of the arm, and supplies the skin of the upper half of the medial and posterior parts of the arm, communicating with the posterior brachial cutaneous branch of the radial nerve. The size of the intercostobrachial nerve is in inverse proportion to that of the medial brachial cutaneous nerve. A second intercostobrachial nerve is frequently given off from the anterior part of the lateral cutaneous branch of the third intercostal nerve; it supplies filaments to the axilla and to the medial side of the arm.

The lower thoracic nerves.—The ventral rami of the seventh, eighth, ninth, tenth, and eleventh thoracic nerves are continued anteriorly from the intercostal spaces into the abdominal wall.

FIG. 971.—A diagram showing the distribution of the cutaneous nerves on the front of the trunk.



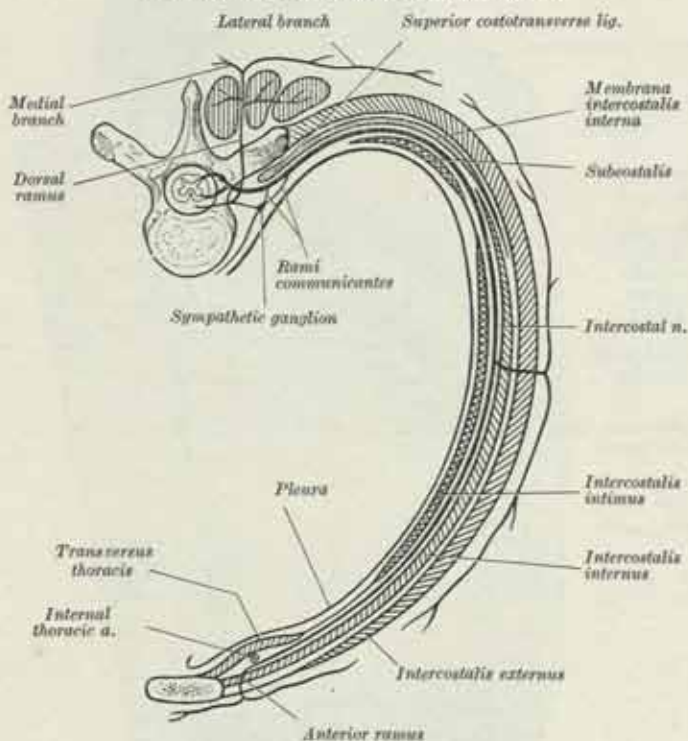
As they approach the anterior ends of the spaces in which they lie, the seventh and eighth nerves curve *upwards* and medially across the deep surface of the costal margin, insinuating themselves between the digitations of the transversus abdominis to gain the deep aspect of the posterior lamella of the aponeurosis of the internal oblique. Having pierced this layer, they lie behind the rectus abdominis muscle and continue upwards and medially (fig. 973) for a short distance parallel with the costal margin. Both supply the rectus abdominis and, having passed through the muscle near its lateral edge, pierce the anterior wall of its sheath, to reach and supply the skin. It will be observed that both the seventh and the eighth intercostal nerves cross the costal margin medial to the lateral border of the rectus abdominis and therefore enter its sheath by piercing its posterior wall.

The ninth, tenth and eleventh intercostal nerves pass between the digitations of the transversus abdominis to gain the interval between that muscle and the internal oblique. In this intermuscular interval the ninth nerve runs almost *horizontally*, but the tenth and eleventh nerves run definitely downwards and medially. When

they reach the lateral edge of the rectus abdominis, they pierce the posterior lamella of the internal oblique aponeurosis and pass behind the muscle. They end like the terminal branches of the seventh and eighth intercostal nerves. The tenth nerve supplies the band of skin which includes the umbilicus (figs. 971 and 987).

The lower intercostal nerves supply the intercostal, the subcostal and the abdominal muscles, and the last three send branches to the serratus posterior inferior. Like the upper intercostal nerves the lower intercostal nerves give off *collateral* and *lateral cutaneous branches* before they reach the angles of the ribs. The collateral branch may, or may not, rejoin the main trunk, but, if it does so, it leaves it again near the lateral border of the rectus abdominis and runs forwards below it (fig. 973). It pierces the muscle and the anterior wall of its sheath near the linea alba and supplies the skin. The lateral cutaneous branches pierce the intercostals and the external oblique muscle, in the same line as the lateral cutaneous branches of the upper thoracic nerves, and divide into anterior and posterior

FIG. 972.—A diagram of the course of a typical intercostal nerve. The muscular and the collateral branches are not shown.



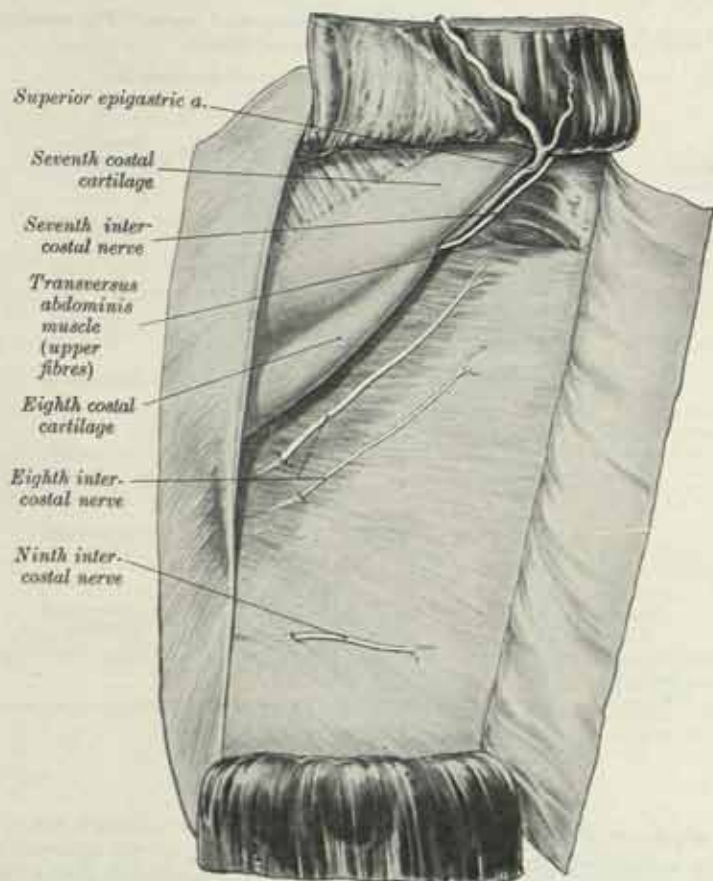
branches, which are distributed to the skin of the abdomen and back respectively; the anterior branches also supply twigs to the digitations of the external oblique muscle, and extend downwards and forwards nearly as far as the margin of the rectus abdominis; the posterior branches pass backwards to supply the skin over the latissimus dorsi. Each lateral cutaneous branch descends as it pierces the external oblique muscle and the superficial fascia so that it reaches the skin on a level with the corresponding anterior cutaneous branch and the cutaneous branch of the corresponding dorsal ramus (p. 1149).

The ventral ramus of the **twelfth thoracic nerve** is larger than the others, and often gives a communicating branch to the first lumbar nerve. Like the intercostal nerves it soon gives off a collateral branch. It accompanies the subcostal artery along the lower border of the twelfth rib, and passes behind the lateral lumbocostal arch. It then runs behind the kidney, and in front of the upper part of the quadratus lumborum, perforates the aponeurosis of origin of the transversus and passes forwards between that muscle and the obliquus internus, to be distributed in the same manner as the lower intercostal nerves. It communicates with the iliohypogastric nerve of the lumbar plexus, and gives a branch to the pyra-

midalis. The *lateral cutaneous branch* of the twelfth thoracic nerve pierces the internal and external oblique muscles, gives a twig to the lowest slip of the latter, descends over the iliac crest about 5 cm. behind the anterior superior iliac spine (fig. 981), and is distributed to the skin of the front part of the buttock, some of its filaments reaching as low as the greater trochanter of the femur.

Applied Anatomy.—In many diseases affecting the nerve-trunks at or near their origins, the pain is referred to their peripheral terminations. Thus, in Pott's disease of the thoracic vertebræ, children often suffer from pain in the abdomen. When the irritation is confined to a single pair of nerves the sensation complained of is often a feeling of constriction, as if a cord were tied round the abdomen, and in these cases the situation of the sense of constriction may serve to localise the disease in the vertebral

FIG. 973.—A dissection to show the courses taken by the seventh, eighth and ninth intercostal nerves of the right side, after they enter the sheath of the rectus abdominis muscle.



The rectus abdominis muscle has been cut across; its upper part has been turned upwards, exposing most of the seventh and the anterior end of the eighth costal cartilage; its lower part has been turned downwards, exposing the posterior wall of the sheath.

column. Where the bone disease is more extensive and two or more nerves are involved, a more general, diffused pain in the abdomen is felt.

Again, it must be borne in mind that the nerves which supply the skin of the abdomen supply also the planes of muscle which constitute the greater part of the abdominal wall, and this is of importance in protecting the abdominal viscera from injury. A blow on the abdomen, even of a severe character, will do no injury to the viscera if the muscles are in a condition of firm contraction; whereas in cases where the muscles have been taken unawares, and the blow has been struck while they were in a state of rest, an injury insufficient to produce any lesion of the abdominal wall has been attended with rupture of some of the abdominal contents. The importance, therefore, of immediate reflex contraction upon the receipt of an injury cannot be overestimated, and the origin of the cutaneous and motor fibres from the same seg-

ments of the spinal cord results in a much more rapid response on the part of the muscles to any peripheral stimulation of the cutaneous filaments than would be the case if the two sets of fibres were derived from independent sources.

The nerves supplying the abdominal muscles and skin, derived from the lower intercostal nerves, are intimately connected with the sympathetic nerves supplying the abdominal viscera through the lower thoracic ganglia, from which the splanchnic nerves are derived. In consequence of this, in laceration of the abdominal viscera, and in acute peritonitis, the muscles of the belly wall become firmly contracted, and thus as far as possible preserve the abdominal contents in a condition of rest.

THE VENTRAL RAMI OF THE LUMBAR NERVES

The **ventral rami of the lumbar nerves** increase in size from the first to the last. They are joined, near their origins, by *grey rami communicantes* from the lumbar ganglia of the sympathetic trunk. These rami consist of long, slender branches which accompany the lumbar arteries round the sides of the vertebral bodies, under cover of the *psoas major*. Their arrangement is somewhat irregular: one ganglion may give rami to two lumbar nerves, or one lumbar nerve may receive rami from two ganglia: not infrequently the rami arise from the sympathetic trunk between two ganglia. The first and second, and sometimes the third, lumbar nerves are each connected with the lumbar part of the sympathetic trunk by a *white ramus communicans*.

The ventral rami of the lumbar nerves pass downwards and laterally behind the *psoas major*, or between its fasciculi. The first three nerves and the greater part of the fourth, form the *lumbar plexus*. The smaller part of the fourth nerve* joins with the fifth to form the *lumbosacral trunk*, which assists in the formation of the sacral plexus.

THE LUMBAR PLEXUS

The **lumbar plexus** (fig. 974) is situated in the posterior part of the *psoas major*, in front of the transverse processes of the lumbar vertebrae; it is formed by the ventral rami of the first three lumbar nerves and the greater part of the ventral ramus of the fourth; the first lumbar nerve receives a branch from the last thoracic nerve.

The mode in which it is arranged varies in different subjects, but the usual condition is the following. The first lumbar nerve, supplemented by a twig from the last thoracic, splits into an upper and a lower branch; the upper, larger branch divides into the *iliohypogastric* and *ilio-inguinal* nerves; the lower, smaller branch unites with a branch of the second lumbar to form the *genitofemoral* nerve. The remainder of the second nerve, the third nerve, and the part of the fourth nerve which joins the plexus, divide into ventral and dorsal branches. The ventral branch of the second unites with the ventral branches of the third and fourth nerves to form the *obturator* nerve. The dorsal branches of the second and third nerves each divide into a smaller and larger part; the smaller parts unite to form the *lateral femoral cutaneous* nerve, and the larger parts join with the dorsal branch of the fourth nerve to form the *femoral* nerve. The accessory obturator, when it exists, arises from the ventral branches of the third and fourth nerves.

The branches of the lumbar plexus may therefore be arranged as follows:

Muscular	12 T., 1, 2, 3, 4 L.
Iliohypogastric	1 L.
Ilio-inguinal	1 L.
Genitofemoral	1, 2 L.

* The fourth nerve is often termed the *nervus furcalis*, from the fact that it is subdivided between the two plexuses. In most cases the fourth lumbar is the *nervus furcalis*; but this arrangement is frequently departed from. The third is occasionally the lowest nerve which enters the lumbar plexus, giving at the same time some fibres to the sacral plexus, and thus forming the *nervus furcalis*; or both the third and fourth may be furcal nerves. When this occurs, the plexus is termed *high* or *prefixed*. More frequently the fifth nerve is divided between the lumbar and sacral plexuses, and constitutes the *nervus furcalis*; and when this takes place, the plexus is distinguished as a *low* or *postfixed* plexus. These variations necessarily produce corresponding modifications in the sacral plexus.

	Dorsal divisions.
Lateral cutaneous, of thigh	2, 3 L.
Femoral	2, 3, 4 L.
	Ventral divisions.
Obturator	2, 3, 4 L.
Accessory obturator	3, 4 L.

Muscular branches are distributed to the quadratus lumborum from the twelfth thoracic and first three or four lumbar nerves; to the psoas minor from the first, to the psoas major from the second, third and, sometimes, from the fourth, and to the iliacus from the second and third lumbar nerves.

The **iliohypogastric nerve** arises from the first lumbar nerve (fig. 974). It emerges from the upper part of the lateral border of the psoas major, and crosses obliquely behind the lower part of the kidney, and in front of the quadratus lumborum. Just above the iliac crest it perforates the posterior part of the transversus abdominis, and divides between that muscle and the obliquus internus abdominis into a lateral and an anterior cutaneous branch.

The *lateral cutaneous branch* pierces the internal and external oblique muscles immediately above the iliac crest at a point a little behind the iliac branch of the twelfth thoracic nerve; it is distributed to the skin of the anterior part of the side of the buttock.

The *anterior cutaneous branch* (fig. 971) runs between the obliquus internus and transversus, supplying twigs to both muscles. It then pierces the obliquus internus at a point about 2 cm. on the medial side of the anterior superior iliac spine, perforates the aponeurosis of the external oblique about 3 cm. above the superficial inguinal ring, and is distributed to the skin of the abdomen above the pubis.

The iliohypogastric nerve communicates with the last thoracic and ilio-inguinal nerves.

The **ilio-inguinal nerve**, smaller than the iliohypogastric nerve, arises with it from the first lumbar nerve (fig. 974). It emerges from the lateral border of the psoas major, with or just below the iliohypogastric nerve, and, passing obliquely across the quadratus lumborum and the upper part of the iliacus, perforates the transversus abdominis, near the anterior part of the iliac crest, and communicates with the iliohypogastric nerve. It then pierces the internal oblique muscle, distributing filaments to it, lies below the spermatic cord in the inguinal canal and accompanies it through the superficial inguinal ring. It is distributed to the skin of the upper and medial part of the thigh, to the skin over the root of the penis and upper part of the scrotum in the male (fig. 971), and to the skin covering the mons pubis and adjoining part of the labium majus in the female.

The size of the ilio-inguinal nerve is in inverse proportion to that of the iliohypogastric. Occasionally it is very small, and ends by joining the iliohypogastric nerve; in such cases, a branch from the iliohypogastric takes the place of the ilio-inguinal, or the latter nerve may be altogether absent. On the analogy of the intercostal nerves the ilio-inguinal nerve may be regarded as the collateral branch (F. Davies, *J. Anat.*, 70, 1935) of the first lumbar nerve, and the iliohypogastric as the main trunk, which gives off the lateral cutaneous branch.

The **genitofemoral nerve** arises from the first and second lumbar nerves (fig. 974). It passes obliquely forwards and downwards through the substance of the psoas major, and emerges on the abdominal surface of the muscle near its medial border, opposite the third or fourth lumbar vertebra; it then descends on the surface of the psoas major, under cover of the peritoneum, and, crossing obliquely behind the ureter, divides at a variable distance above the inguinal ligament into the genital and femoral branches. The genitofemoral nerve frequently divides close to its origin, and its two branches then emerge separately through the psoas major.

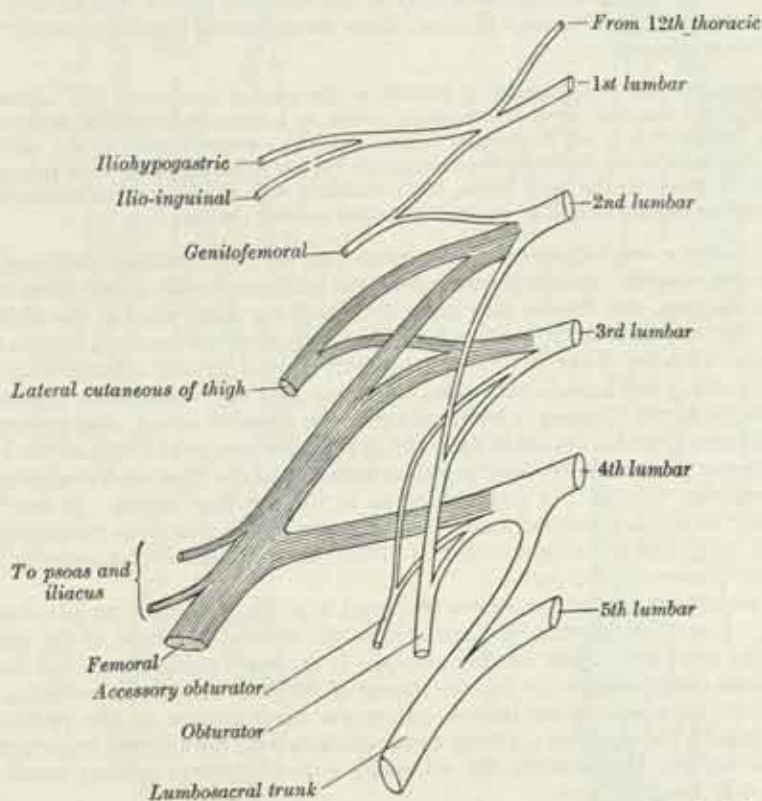
The *genital branch* crosses the lower end of the external iliac artery, and enters the inguinal canal through the deep inguinal ring; it supplies the cremaster, and gives a few filaments to the skin of the scrotum. In the female, it accompanies the round ligament of the uterus and ends in the skin of the mons pubis and labium majus.

The *femoral branch* descends on the lateral side of the external iliac artery, and sends a few filaments round it; it then crosses the deep circumflex iliac artery, and

passing behind the inguinal ligament, enters the femoral sheath, lying lateral to the femoral artery. It pierces the anterior layer of the femoral sheath and the fascia lata, and supplies the skin over the upper part of the femoral triangle (fig. 975). It communicates with the intermediate cutaneous nerve of the thigh, and gives a few twigs to the femoral artery.

The **lateral cutaneous nerve of the thigh** arises from the dorsal branches of the ventral rami of the second and third lumbar nerves (fig. 974). It emerges from the lateral border of the *psoas major*, and crosses the *iliacus* obliquely, running towards the anterior superior iliac spine. On the right side the nerve passes behind and lateral to the cæcum, from which it is separated by the fascia iliaca and the peritoneum; on the left side, it passes behind the lower part of the descending colon. It then passes behind the inguinal ligament and in front of or through the

FIG. 974.—A plan of the lumbar plexus.



Note.—The dorsal divisions of the second, third and fourth lumbar nerves are shaded.

sartorius into the thigh, where it divides into an anterior and a posterior branch (fig. 975).

The **anterior branch** becomes superficial about 10 cm. below the anterior superior iliac spine, and is distributed to the skin of the anterior and lateral parts of the thigh, as far as the knee. Its terminal filaments frequently communicate with the cutaneous branches of the anterior division of the femoral nerve and with the infrapatellar branch of the saphenous nerve, forming with them the *patellar plexus*.

The **posterior branch** pierces the fascia lata at a higher level than the anterior branch, and subdivides into filaments which pass backwards to supply the skin on the lateral surface of the limb, from the level of the greater trochanter to about the middle of the thigh. It may also supply twigs to the skin of the gluteal region.

The **obturator nerve** arises from the ventral branches of the ventral rami of the second, third, and fourth lumbar nerves (fig. 974); the branch from the third is the largest, while that from the second is often very small. It descends through the fibres of the *psoas major*, and emerges from its medial border at the brim of the

pelvis, where it passes behind the common iliac vessels, and on the lateral side of the internal iliac vessels. It then runs downwards and forwards along the lateral wall of the lesser pelvis lying on the obturator internus, above and in front of the obturator vessels, to gain the upper part of the obturator foramen, through which it enters the thigh. At the foramen it divides into an anterior and a posterior branch, which are separated at first by a few fibres of the obturator externus, and lower down by the adductor brevis.

The *anterior branch* (fig. 977) leaves the pelvis in front of the obturator externus and descends in front of the adductor brevis, and behind the pectineus and adductor longus; at the lower border of the latter muscle it communicates with the medial cutaneous and saphenous branches of the femoral nerve, forming a kind of plexus (often termed the *subsartorial plexus*). It then descends upon the femoral artery, to which it is finally distributed. Near the obturator foramen this branch gives an articular twig to the hip-joint. Behind the pectineus, it distributes branches to the adductor longus and gracilis, and usually to the adductor brevis, and in rare cases to the pectineus; it receives a filament from the accessory obturator nerve when that nerve is present.

Occasionally the communicating branch to the medial cutaneous and saphenous branches of the femoral nerve is continued down, as a cutaneous branch, to the thigh and leg. When this is so, it emerges from behind the lower border of the adductor longus, descends along the posterior margin of the sartorius to the medial side of the knee, where it pierces the deep fascia, communicates with the saphenous nerve, and is distributed to the skin halfway down the medial side of the leg.

The *posterior branch* pierces the anterior part of the obturator externus, and supplies this muscle; it then passes behind the adductor brevis on the front of the adductor magnus, and divides into branches which are distributed to the adductor magnus, and to the adductor brevis when this muscle does not receive a branch from the anterior division of the nerve. It frequently gives a slender *articular branch* to the knee-joint; this branch perforates the lower part of the adductor magnus or passes through the opening which transmits the femoral artery, and enters the popliteal fossa. Here it descends upon the popliteal artery, to the back of the knee-joint, where it pierces the oblique posterior ligament of the knee, and is distributed to the articular capsule. It gives filaments to the popliteal artery. It has been described * as receiving one or more communicating branches from the saphenous nerve (p. 1179) and as being distributed to the posterior part of the capsular ligament in its supero-medial part.

The *accessory obturator nerve* (fig. 974) is present in about 29 per cent. of subjects. It is of small size, and arises from the ventral branches of the ventral rami of the third and fourth lumbar nerves. It descends along the medial border of the psoas major, crosses the superior ramus of the pubis behind the pectineus, and divides into branches. One branch enters the deep surface of the pectineus; another goes to the hip-joint; a third communicates with the anterior branch of the obturator nerve. Occasionally the accessory obturator nerve is very small and supplies only the pectineus.

The *femoral nerve* (fig. 974), the largest branch of the lumbar plexus, arises from the dorsal branches of the ventral rami of the second, third and fourth lumbar nerves (fig. 974). It descends through the fibres of the psoas major, emerging from the muscle at the lower part of its lateral border, and passes down between it and the iliacus, deep to the iliac fascia; it then passes behind the inguinal ligament to enter the thigh, and splits into an anterior and a posterior division. Behind the inguinal ligament it is separated from the femoral artery by a portion of the psoas major.

Within the abdomen the femoral nerve gives off small branches to the iliacus, the nerve to the pectineus, and a branch which is distributed upon the upper part of the femoral artery; the latter branch may arise in the thigh. The *nerve to the pectineus* arises from the medial side of the femoral nerve near the inguinal ligament, passes behind the femoral sheath and enters the anterior surface of the muscle.

The anterior division of the femoral nerve gives off the intermediate and medial cutaneous nerves of the thigh (fig. 975), and muscular branches to the sartorius.

* Gardner, Ernest, *Anat. Rec.*, 101, 1948.

The *intermediate cutaneous nerve of the thigh* pierces the fascia lata about 8 cm. below the inguinal ligament, either as two branches, or as a single trunk

FIG. 975.—The cutaneous nerves of the right lower limb. Anterior surface.

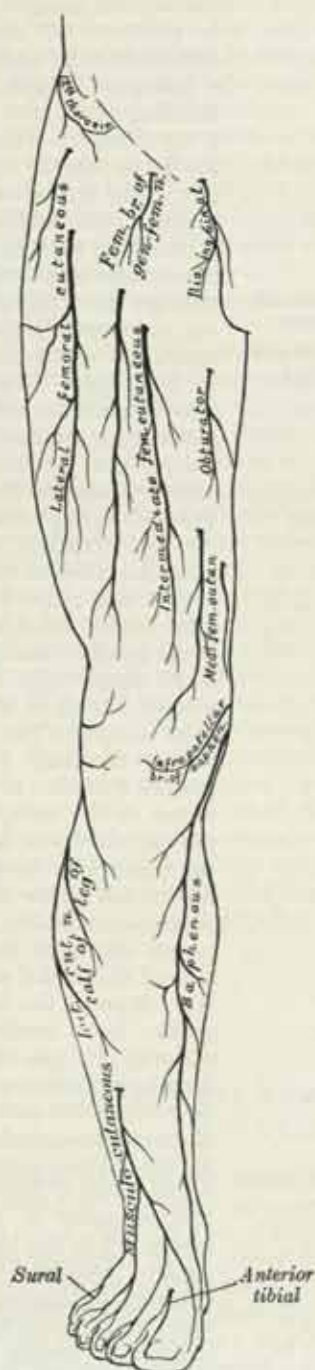
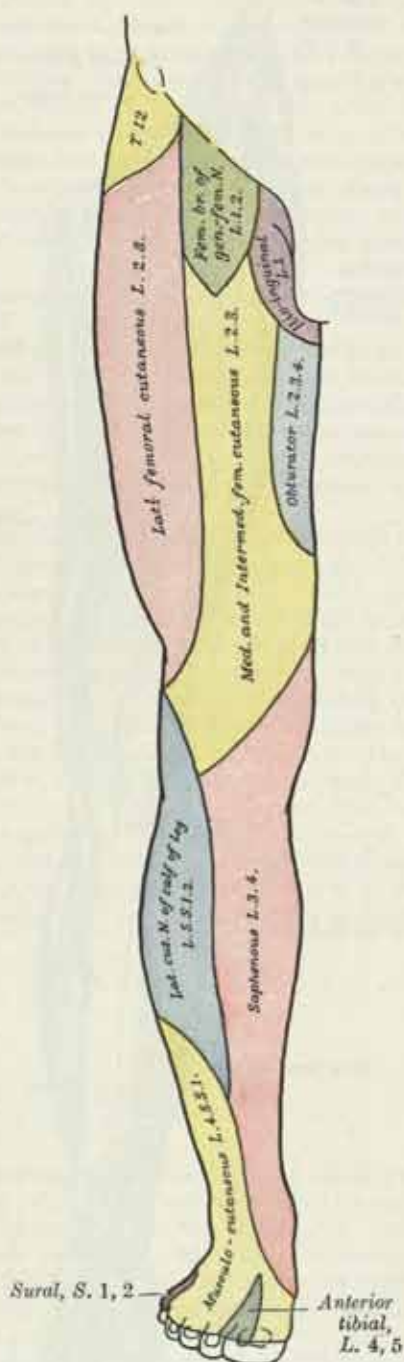


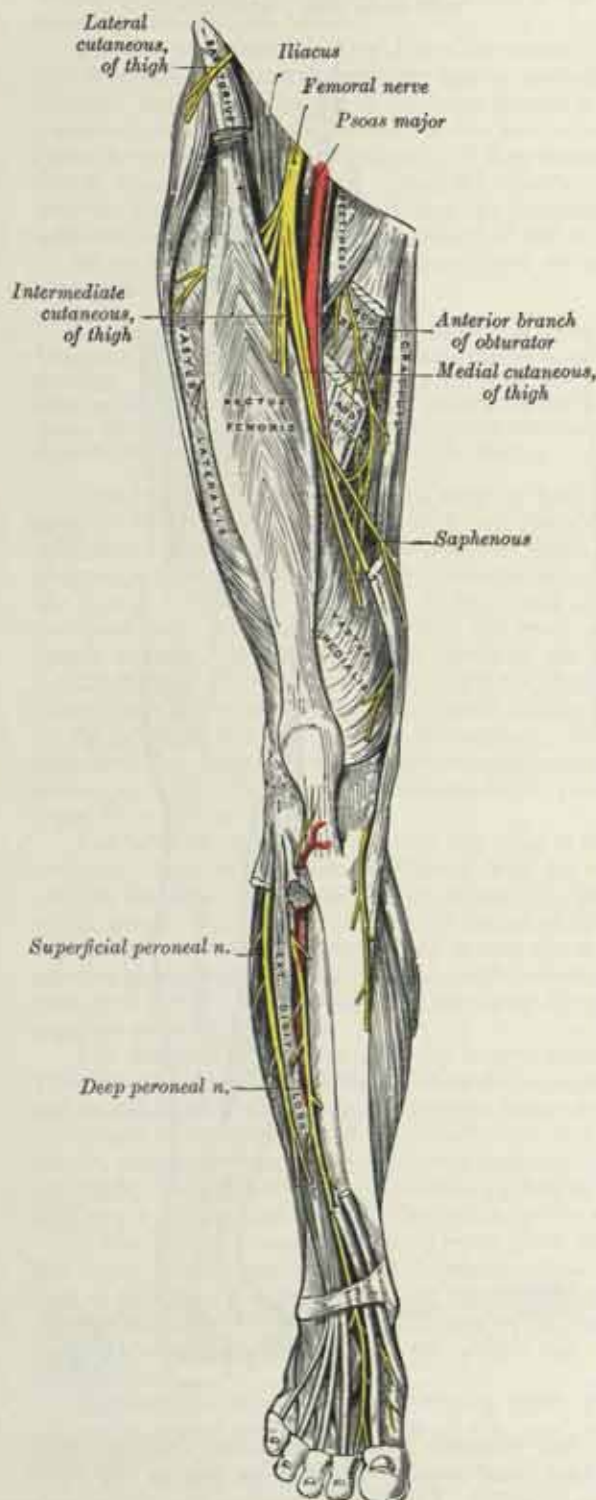
FIG. 976.—A diagram showing the segmental distribution of the cutaneous nerves of the right lower limb. Anterior surface.



which quickly divides into two branches; these branches descend vertically on the front of the thigh, and supply the skin as low as the knee. They end in the patellar plexus (p. 1179). The lateral branch of the intermediate

cutaneous communicates with the femoral branch of the genitofemoral nerve, and frequently pierces the sartorius, to which it may give a branch of supply.

FIG. 977.—The nerves of the right lower limb.
Anterior surface.



The *medial cutaneous nerve of the thigh* lies at first on the lateral side of the femoral artery, but at the apex of the femoral triangle it crosses in front of the artery and divides into an anterior and a posterior branch. Before dividing, the nerve gives off a few filaments which pierce the fascia lata to supply the skin of the medial side of the thigh, in the neighbourhood of the long saphenous vein; one of these filaments emerges through the saphenous opening, and a second becomes sub-cutaneous about the middle of the thigh. The *anterior branch* runs downwards on the sartorius, perforates the fascia lata at the junction of the middle with the lower one-third of the thigh, and divides into two branches: one supplies the skin as low as the medial side of the knee; the other crosses to the lateral side of the patella, communicating in its course with the infra-patellar branch of the saphenous nerve. The *posterior branch* descends along the posterior border of the sartorius to the knee, where it pierces the fascia lata, communicates with the saphenous nerve, and gives off several cutaneous branches. It then passes down to supply the skin of the medial side of the leg. Beneath the fascia lata, at the lower border of the adductor longus, it joins to form a plexiform network (*sub-sartorial plexus*) with branches of the saphenous and obturator nerves. When the communicating branch from the obturator nerve is large and continued to the skin of the leg, the posterior branch of the medial cutaneous is small, and terminates in the plexus, occasionally giving off a few cutaneous filaments.

The *nerve to the sartorius* arises in common with the intermediate cutaneous nerve of the thigh.

The posterior division of the femoral nerve gives off the saphenous nerve, and supplies muscular branches to the quadriceps femoris, and articular branches to the knee-joint.

The **saphenous nerve** (fig. 977) is the largest cutaneous branch of the femoral nerve. It descends on the lateral side of the femoral artery and enters the adductor canal (p. 819) where it crosses the artery obliquely from its lateral to its medial side. At the lower end of the canal it quits the artery, and emerges through the aponeurotic covering of the canal, accompanied by the saphenous branch of the descending genicular artery. It descends vertically along the medial side of the knee behind the sartorius, pierces the fascia lata between the tendons of the sartorius and gracilis, and becomes subcutaneous. It then passes down the tibial side of the leg accompanied by the long saphenous vein, descends along the medial border of the tibia, and, at the lower third of the leg, divides into two branches: one continues its course along the margin of the tibia, and ends at the ankle; the other passes in front of the ankle, and is distributed to the skin on the medial side of the foot, often reaching as far as the ball of the great toe and communicating with the medial branch of the musculocutaneous nerve.

About the middle of the thigh, the saphenous nerve gives a branch to join the subsartorial plexus.

After leaving the adductor canal it gives off an *infrapatellar branch* (fig. 975), which pierces the sartorius and fascia lata, and is distributed to the skin in front of the patella. Above the knee this nerve unites with the medial and intermediate cutaneous nerves of the thigh; below the knee, with other branches of the saphenous nerve; and, on the lateral side of the joint, with branches of the lateral cutaneous nerve of the thigh, forming a plexiform network, termed the *patellar plexus*. The infrapatellar branch is occasionally small.

The *muscular branches* of the posterior division of the femoral nerve supply the quadriceps femoris. The branch to the rectus femoris enters the upper part of the deep surface of the muscle, and supplies a filament to the hip-joint. The branch to the vastus lateralis, of large size, accompanies the descending branch of the lateral circumflex femoral artery to the lower part of the muscle, and sends an articular filament to the knee-joint. The branch to the vastus medialis descends through the upper part of the adductor canal, on the lateral side of the saphenous nerve and the femoral vessels. It enters the muscle about its middle, and gives off a filament which can usually be traced downwards on the surface of the muscle, to the knee-joint. The branches to the vastus intermedius, two or three in number, enter the anterior surface of the muscle about the middle of the thigh; a filament from one of these descends through the muscle to the articularis genu and the knee-joint.

A separate *articular branch* to the knee-joint has been described,* and is said to communicate with the articular branch of the obturator nerve (p. 1176) in the adductor canal, thereafter descending to supply the medial part of the capsular ligament of the knee-joint.

THE VENTRAL RAMI OF THE SACRAL AND COCCYGEAL NERVES

The **ventral rami of the sacral and coccygeal nerves** form the sacral and coccygeal plexuses. Those of the upper four sacral nerves enter the pelvis through the pelvic sacral foramina, that of the fifth between the sacrum and coccyx, while that of the coccygeal nerve curves forwards below the rudimentary transverse process of the first piece of the coccyx. The first and second sacral nerves are large; the third, fourth and fifth diminish progressively; the coccygeal nerve is the smallest. Each of these nerves receives a *grey ramus communicans* from the corresponding ganglion of the sympathetic trunk. *Visceral efferent fibres* arise from the second, third and fourth sacral nerves; they are named the *pelvic splanchnic nerves* (fig. 1000), and consist of parasympathetic fibres which pass directly to minute ganglia on the walls of the pelvic viscera (p. 1200).

* Gardner, Ernest, *Anat. Rec.*, 101, 1948.

THE SACRAL PLEXUS

The **sacral plexus** (fig. 978) is formed by the lumbosacral trunk, the ventral rami of the first, second, and third sacral nerves, and part of the ventral ramus of the fourth sacral nerve.

The lumbosacral trunk comprises a part of the ventral ramus of the fourth lumbar nerve, and the whole of the ventral ramus of the fifth lumbar nerve; it appears at the medial margin of the psoas major and descends over the pelvic brim and in front of the sacro-iliac joint to join the first sacral nerve.

The ventral ramus of the fourth sacral nerve divides into an upper and a lower branch; the upper branch enters the sacral plexus; the lower descends to assist in forming the coccygeal plexus.

Relations.—The sacral plexus lies on the posterior wall of the pelvic cavity in front of the piriformis (fig. 979), and behind the internal iliac vessels, the ureter and the sigmoid colon, on the left side, and the terminal coils of the ileum, on the right side. The superior gluteal vessels run between the lumbosacral trunk and the first sacral nerve, or between the first and second sacral nerves, and the inferior gluteal vessels between the ventral rami of the first and second, or second and third, sacral nerves.

The nerves forming the sacral plexus converge towards the lower part of the greater sciatic foramen, and unite to form a flattened band, from the anterior and posterior surfaces of which several branches arise; the band itself is continued as the sciatic nerve.

As shown in the following table, the fibres of the nerves which form the plexus can be traced into branches which may be morphologically ventral, or dorsal, or mixed.

	Ventral divisions.	Dorsal divisions.
Nerve to quadratus femoris and gemellus inferior	4, 5 L., 1 S.	
Nerve to obturator internus and gemellus superior		
Nerve to piriformis	5 L., 1, 2 S.	(1) 2 S.
Superior gluteal		4, 5 L., 1 S.
Inferior gluteal		5 L., 1, 2 S.
Posterior femoral cutaneous	2, 3 S.	1, 2 S.
Sciatic { Tibial	4, 5 L., 1, 2, 3 S.	
{ Common peroneal		4, 5 L., 1, 2 S.
Perforating cutaneous		2, 3 S.
Pudendal	2, 3, 4 S.	
Nerves to levator ani, coccygeus and sphincter ani externus	4 S.	
Pelvic splanchnics	2, 3, (4) S.	

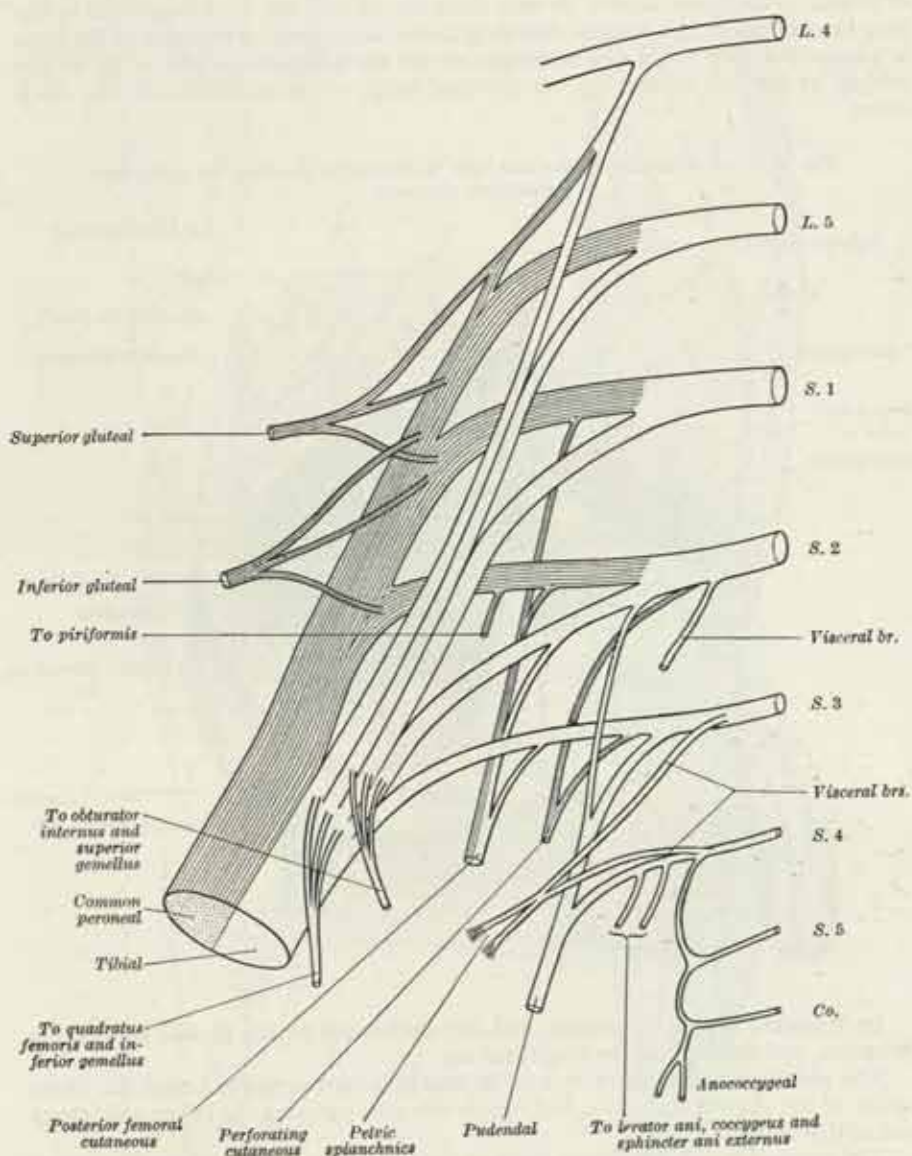
The **nerve to the quadratus femoris and gemellus inferior** arises from the ventral branches of the ventral rami of the fourth and fifth lumbar and first sacral nerves (fig. 978); it leaves the pelvis through the greater sciatic foramen below the piriformis, and, running down on the ischium deep to the sciatic nerve, the gemelli and the tendon of the obturator internus, supplies a twig to the gemellus inferior, and enters the anterior surface of the quadratus femoris; it gives an articular branch to the hip-joint.

The **nerve to the obturator internus and gemellus superior** arises from the ventral branches of the ventral rami of the fifth lumbar and first and second sacral nerves (fig. 978). It leaves the pelvis through the greater sciatic foramen below the piriformis, and gives a branch which enters the upper part of the posterior surface of the gemellus superior. It then crosses the ischial spine on the lateral side of the internal pudendal vessels, re-enters the pelvis through the lesser sciatic foramen, and pierces the pelvic surface of the obturator internus.

The **nerve to the piriformis** arises usually from the dorsal branches of the ventral rami of the first and second sacral nerves; it enters the anterior surface of the muscle.

The **superior gluteal nerve** arises from the dorsal branches of the ventral rami of the fourth and fifth lumbar and first sacral nerves (fig. 978): it leaves the pelvis through the greater sciatic foramen above the piriformis, accompanied by the superior gluteal vessels, and divides into a superior and an inferior branch.

FIG. 978.—A plan of the sacral and coccygeal plexuses.



Note.—The ventral divisions of the spinal nerves concerned and their derivatives are unshaded: the dorsal divisions and their derivatives are shaded.

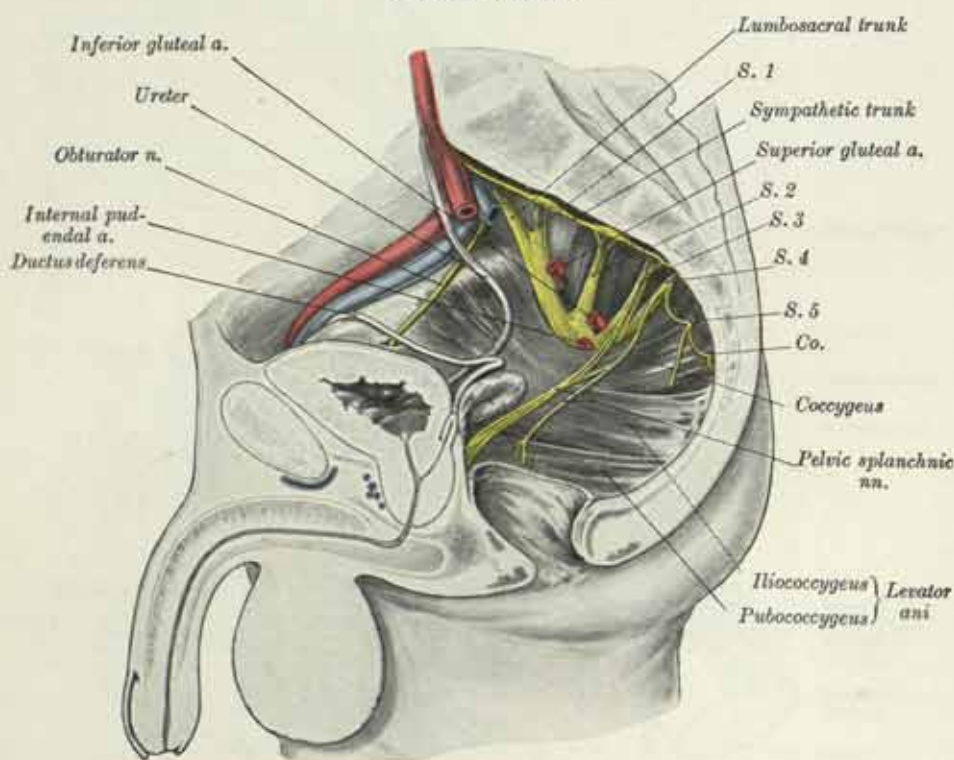
The **superior branch** accompanies the upper branch of the deep division of the superior gluteal artery and supplies branches to the gluteus medius and occasionally also to the gluteus minimus. The **inferior branch** runs with the lower branch of the deep division of the superior gluteal artery across the gluteus minimus; it gives twigs to the gluteus medius and gluteus minimus, and ends in the tensor fasciæ latae.

The **inferior gluteal nerve** arises from the dorsal branches of the ventral rami of the fifth lumbar and first and second sacral nerves: it leaves the pelvis through

the greater sciatic foramen, below the piriformis, and divides into branches which enter the deep surface of the gluteus maximus.

The **posterior cutaneous nerve of the thigh** arises from the dorsal branches of the ventral rami of the first and second, and from the ventral branches of the ventral rami of the second and third, sacral nerves (fig. 978), and issues from the pelvis through the greater sciatic foramen below the piriformis. It then descends under cover of the gluteus maximus with the inferior gluteal artery, lying posterior or medial to the sciatic nerve. It runs down the back of the thigh superficial to the long head of the biceps femoris, and deep to the fascia lata: at the back of the knee it pierces the deep fascia and accompanies the short saphenous vein as far as the middle of the calf of the leg, its terminal twigs communicating with the sural nerve.

FIG. 979.—A dissection of the side wall of the pelvis, showing the sacral and coccygeal plexuses.



Its branches are all cutaneous, and are distributed to the gluteal region, the perineum, and the back of the thigh and leg.

The *gluteal branches*, three or four in number, turn upwards round the lower border of the gluteus maximus, and supply the skin covering the lower and lateral part of that muscle.

The *perineal branch* distributes twigs to the skin at the upper and medial side of the thigh, and then curves forwards across the origin of the hamstrings, below the ischial tuberosity; it pierces the fascia lata, and runs beneath the superficial fascia of the perineum to the skin of the scrotum in the male, and of the labium majus in the female, joining with the inferior rectal and the scrotal branches of the perineal nerve.

The *branches to the back of the thigh and leg* consist of numerous filaments derived from both sides of the nerve, and distributed to the skin covering the back and medial side of the thigh, the popliteal fossa and the upper part of the back of the leg (fig. 980).

The **sciatic nerve** (figs. 978, 982) is the largest nerve in the body and at its commencement it measures 2 cm. in breadth. It is the continuation of

the flattened band of the sacral plexus. It passes out of the pelvis through the greater sciatic foramen, below the piriformis muscle, descends between the

FIG. 980.—The cutaneous nerves of the right lower limb. Posterior surface.

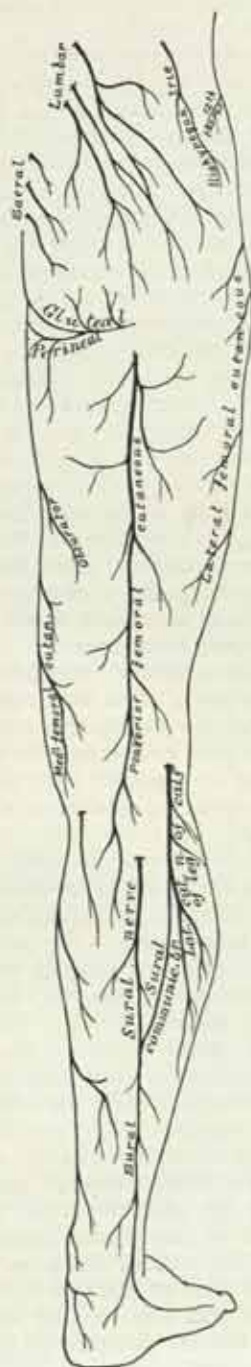
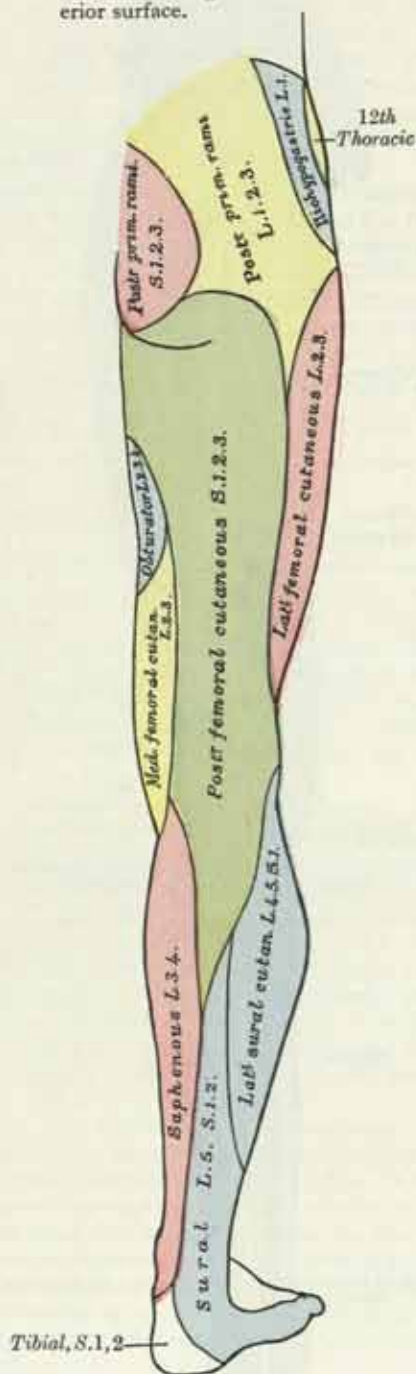


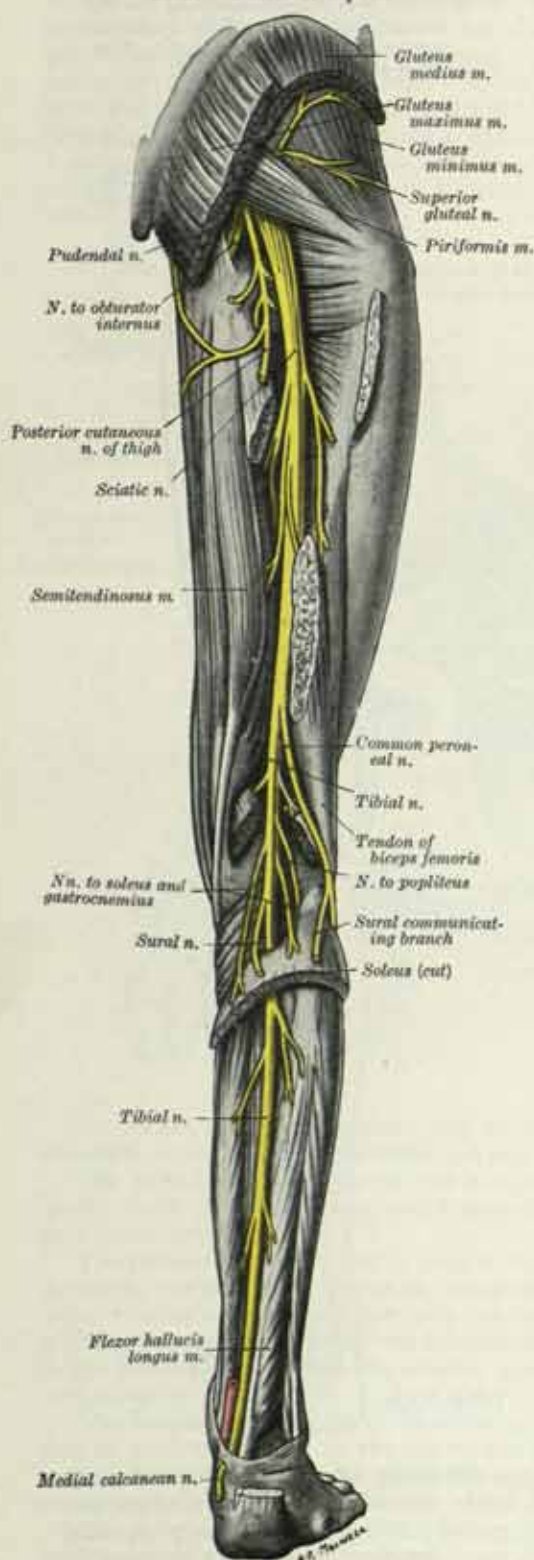
FIG. 981.—A diagram showing the segmental distribution of the cutaneous nerves of the right lower limb. Posterior surface.



greater trochanter of the femur and the tuberosity of the ischium, and along the back of the thigh to about its lower one-third, where it divides into two large branches, named the tibial (medial popliteal) and common peroneal (lateral popliteal) nerves. This division may take place at any point between the

sacral plexus and the lower one-third of the thigh," and in all cases the independence

FIG. 982.—The nerves of the right lower limb.* Posterior aspect.



of the two nerves can be shown by dissection. When the division occurs at the plexus, the common peroneal nerve usually pierces the piriformis. The nerve also gives off articular and muscular branches.

In the upper part of its course the nerve is placed under cover of the gluteus maximus, and rests first upon the posterior surface of the ischium, the nerve to the quadratus femoris intervening; it then crosses the obturator internus and gemelli, and passes on to the quadratus femoris, by which it is separated from the obturator externus and the hip-joint; it is accompanied on its medial side by the posterior cutaneous nerve of the thigh and the inferior gluteal artery. Lower down it lies upon the adductor magnus, and is crossed obliquely by the long head of the biceps femoris. It can be represented on the back of the thigh by a broad line drawn downwards to the apex of the popliteal fossa from just medial to the midpoint of the line joining the ischial tuberosity to the apex of the greater trochanter.

The *articular branches* of the sciatic nerve arise from the upper part of the nerve, and supply the hip-joint by perforating the posterior part of its capsule; they are sometimes derived directly from the sacral plexus.

The *muscular branches* of the sciatic nerve are distributed to the biceps femoris, semitendinosus, semimembranosus and to the ischial head of the adductor magnus (p. 663); the branches to the two latter arise by a common trunk. The nerve to the short head of the biceps femoris comes from the common peroneal part, while the other muscular branches arise from the tibial portion of the sciatic nerve.

The **tibial (medial popliteal) nerve** (fig. 982), the larger, terminal branch of the sciatic nerve, arises from the ventral branches of the ventral rami of the fourth and fifth lumbar and first, second and third sacral nerves. It descends along the

* N.B.—In this figure the gluteus maximus, the gluteus medius and the superficial muscles of the calf of the leg have been removed and the middle part of the long head of the biceps femoris has been excised.

back of the thigh and through the middle of the popliteal fossa, to the lower border of the popliteus muscle, where it passes with the popliteal artery deep to the arch of soleus. Thereafter it is continued into the leg. In the thigh it is overlapped by the hamstring muscles above, but it becomes more superficial in the popliteal fossa, where it lies lateral to, and some distance from, the popliteal vessels; it is superficial to these vessels opposite the knee-joint and then crosses to the medial side of the popliteal artery (fig. 983). In the lower part of the popliteal fossa, the nerve is covered by the contiguous margins of the two heads of the gastrocnemius. It can be represented by a line drawn downwards in the middle line of the limb from the apex of the popliteal fossa to the level of the neck of the fibula. Continued downwards to a point midway between the medial malleolus and the tendo calcaneus, the line maps out the whole course of the tibial nerve.

In the leg it descends in company with the posterior tibial vessels to the interval between the heel and the medial malleolus, where it ends under cover of the flexor retinaculum by dividing into the medial and lateral plantar nerves. In the upper part of its course it is covered posteriorly by the soleus and gastrocnemius muscles, but in the lower third of the leg it is covered only by the skin and fasciae, although it is overlapped sometimes by the medial edge of the flexor hallucis longus muscle. Above, it lies on the medial side of the posterior tibial vessels, but it soon crosses behind them and descends to its point of bifurcation along their lateral side. In most of its course it lies on the tibialis posterior muscle, but in the lower part of the leg it comes into relation with the posterior surface of the tibia.

The branches of this nerve are articular, muscular, sural, medial calcanean and medial and lateral plantar.

Articular branches, usually three in number, supply the knee-joint; one branch accompanies the superior, and another the inferior medial genicular artery; the third branch runs with the middle genicular artery. In the foetus these branches may all arise by a common trunk* which usually leaves the tibial nerve high up in the popliteal fossa but is variable in its point of origin. Descending on the popliteal artery it forms a plexus with the articular branch of the obturator nerve and is distributed, for the most part, to the oblique posterior ligament of the knee-joint. Small branches leave the plexus to accompany the superior and inferior medial genicular arteries and supply the medial parts of the capsular ligament. Another articular branch arises from the nerve just above its terminal bifurcation, and supplies the ankle-joint.

The *muscular branches* arise from the nerve as it lies between the two heads of the gastrocnemius muscle; they supply that muscle, as well as the plantaris, soleus and popliteus. The nerve to the soleus enters the superficial surface of the muscle. The branch for the popliteus descends, crossing the popliteal vessels obliquely, and turns round the lower border of the muscle to be distributed to its deep surface; it supplies small branches to the tibialis posterior, an articular twig to the upper tibiofibular joint, a medullary branch to the tibia, and an interosseous branch, which descends close to the fibula, and can be traced to the inferior tibiofibular joint.

In the leg, the muscular branches arise either independently or by a common trunk. They supply the soleus, on its deep surface, the tibialis posterior, the flexor digitorum longus and the flexor hallucis longus; the branch to the last muscle accompanies the peroneal vessels.

The *sural nerve* descends between the two heads of the gastrocnemius, and, piercing the deep fascia about the middle of the back of the leg, is joined by the sural communicating branch of the common peroneal nerve (fig. 980). It then passes downwards near the lateral margin of the tendo calcaneus, and close to the small saphenous vein, to the interval between the lateral malleolus and the calcaneum; it supplies the skin of the lateral and posterior part of the lower one-third of the leg. It runs forwards below the lateral malleolus, and is continued along the lateral side of the foot and little toe, communicating on the dorsum of the foot with the superficial peroneal nerve. In the leg, its branches communicate with those of the posterior cutaneous nerve of the thigh.

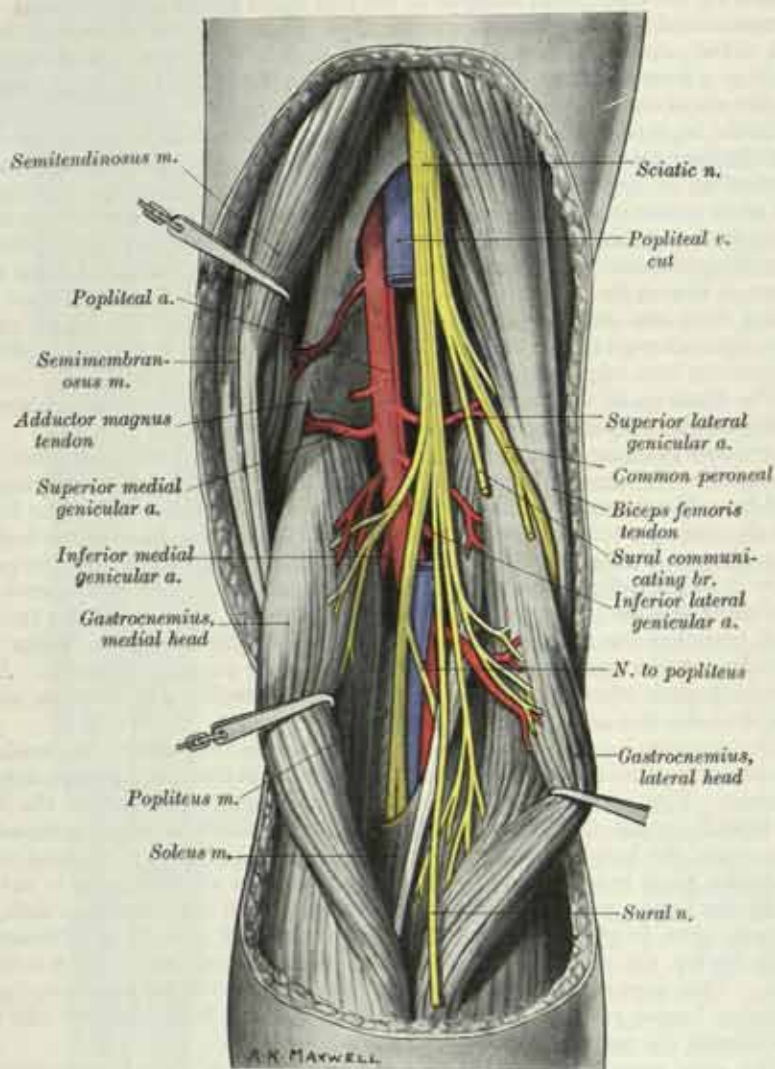
The *medial calcanean branches* perforate the flexor retinaculum, and supply the skin of the heel and medial side of the sole of the foot.

The *medial plantar nerve* (fig. 984), the larger of the two terminal divisions of the tibial nerve, accompanies the medial plantar artery and lies on the lateral side

* Gardner, Ernest, *Anat. Rec.*, 101, 1948.

of the vessel. From its origin under cover of the flexor retinaculum it passes deep to the abductor hallucis, and, appearing between this muscle and the flexor digi-

FIG. 983.—A dissection of the right popliteal fossa. The two heads of Gastrocnemius, and the Semitendinosus and Semimembranosus have been retracted in order to expose the contents of the fossa more fully.



torum brevis, gives off a digital nerve to the medial side of the great toe and finally divides opposite the bases of the metatarsal bones into three plantar digital nerves.

Branches.—*Cutaneous branches* pierce the plantar aponeurosis between the abductor hallucis and the flexor digitorum brevis and are distributed to the skin of the sole of the foot.

Muscular branches supply the abductor hallucis, the flexor digitorum brevis, the flexor hallucis brevis and the first lumbrical muscle; those for the abductor hallucis and flexor digitorum brevis arise from the trunk of the nerve near its origin and enter the deep surfaces of the muscles; the branch for the flexor hallucis brevis springs from the digital nerve to the medial side of the great toe, and that for the first lumbrical muscle from the first plantar digital nerve.

Articular branches supply the articulations of the tarsus and metatarsus.

The *digital nerve of the great toe* supplies the flexor hallucis brevis and the skin on the medial side of the great toe.

The *three plantar digital nerves* pass between the divisions of the plantar aponeurosis, and each splits into two branches. Those of the first plantar digital nerve supply the adjacent sides of the great and second toes; those of the second, the adjacent sides of the second and third toes; and those of the third, the adjacent sides of the third and fourth toes. The third plantar digital nerve receives a communicating branch from the lateral plantar nerve; the first gives a twig to the first

FIG. 984.—The plantar nerves of the right foot.

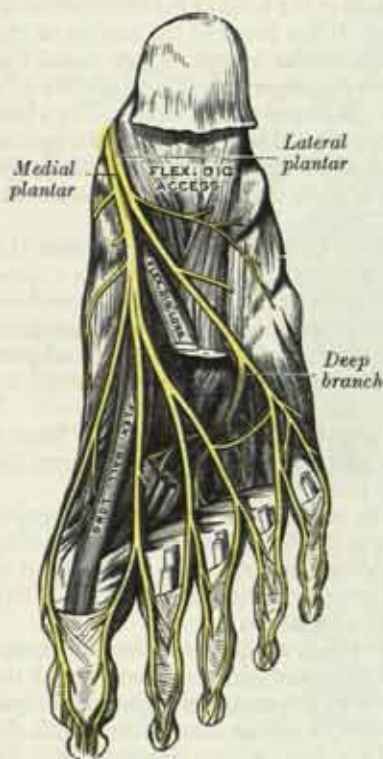
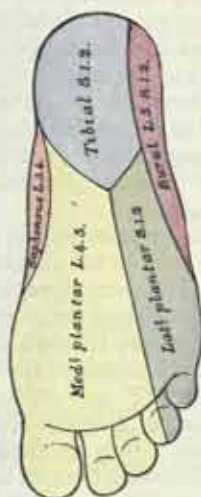


FIG. 985.—A diagram showing the distribution of the cutaneous nerves of the sole of the right foot.



lumbrical muscle. Each digital branch gives off cutaneous and articular filaments and opposite the distal phalanx sends upwards a dorsal branch, which supplies the structures around the nail, the continuation of the nerve being distributed to the ball of the toe. *It will be observed that the digital branches of the medial plantar nerve are similar in their distribution to those of the median nerve in the hand. The muscles*

supplied by the two nerves also correspond closely. In the hand, the median nerve supplies the abductor and the flexor pollicis brevis, the opponens pollicis and the first and second lumbricals. The opponens muscle is absent in the foot, but the abductor and short flexor of the great toe and the first lumbrical are all supplied by the medial plantar nerve. As the flexor digitorum brevis corresponds to the flexor digitorum superficialis (median nerve) of the upper limb, the only real difference consists in the innervation of the second lumbrical muscle.

The **lateral plantar nerve** (fig. 984) supplies the skin of the fifth toe and lateral half of the fourth, as well as most of the deep muscles, *its distribution being similar to that of the ulnar nerve in the hand.* It passes forwards obliquely in company with the lateral plantar artery, which lies on the lateral side of the nerve, and reaches the lateral side of the foot near the tubercle of the fifth metatarsal bone. It passes between the flexor digitorum brevis and the flexor accessorius, and ends in the interval between the former muscle and the abductor digiti minimi by dividing into a superficial and a deep branch. Before its division, it supplies the flexor accessorius and abductor digiti minimi and gives off some small cutaneous branches which pierce the plantar fascia and supply the skin of the lateral part of the sole of the foot (fig. 985).

The *superficial branch* splits into two plantar digital nerves; of these the lateral supplies the lateral side of the little toe, the flexor digiti minimi brevis, and the two interosseous muscles of the fourth intermetatarsal space; the medial communicates

with the third plantar digital branch of the medial plantar nerve and divides into two branches which supply the adjoining sides of the fourth and fifth toes.

The *deep branch* accompanies the lateral plantar artery on the deep surface of the tendons of the flexor muscles and the adductor hallucis, and supplies the second, third and fourth lumbricals, the adductor hallucis and all the interosseous muscles (except those of the fourth intermetatarsal space). The nerves to the second and third lumbricals pass distally deep to the transverse head of the adductor hallucis, and then pass round its distal border to reach the muscles (fig. 986).

The **common peroneal (lateral popliteal) nerve** (fig. 983), about one-half the size of the tibial nerve is derived from the dorsal branches of the ventral rami of the fourth and fifth lumbar and the first and second sacral nerves. It descends obliquely along the lateral side of the popliteal fossa to the head of the fibula, close to the medial margin of the biceps femoris muscle. It lies between the tendon of the biceps femoris and the lateral head of the gastrocnemius muscle, winds round the lateral surface of the neck of the fibula deep to the peroneus longus, and divides into the musculocutaneous and anterior tibial nerves. Its course can be indicated by a line drawn from the apex of the popliteal fossa downwards and laterally, along the medial side of the biceps tendon, to the back of the head of the fibula, *where the nerve can be rolled against the bone*. Previous to its division it gives off articular and cutaneous branches.

The *articular branches* are three in number; of these one accompanies the superior and another the inferior lateral genicular artery. Both may arise by a common trunk. The third, named the recurrent articular nerve, is given off at or near the point of division of the common peroneal nerve; it ascends with the anterior recurrent tibial artery through the tibialis anterior to supply the antero-lateral part of the capsular ligament of the knee-joint and also supplies branches to the superior tibio-fibular joint.*

The *cutaneous branches* (fig. 980), two in number, frequently spring from a common trunk; they are the lateral cutaneous nerve of the calf of the leg and the sural communicating branch.

The *lateral cutaneous nerve of the calf of the leg* supplies the skin on the anterior, posterior and lateral surfaces of the proximal part of the leg. The *sural communicating branch* arises near the head of the fibula, runs obliquely across the lateral head of the gastrocnemius to the middle of the leg, and joins with the sural nerve (p. 1185). It may, however, descend as a separate branch as far as the heel.

The **deep peroneal (anterior tibial) nerve** (fig. 976) begins at the bifurcation of the common peroneal nerve, between the fibula and the proximal part of the peroneus longus, passes obliquely forwards deep to the extensor digitorum longus to the front of the interosseous membrane, where it comes into relation with the anterior tibial artery in the upper one-third of the leg; it then descends with the artery to the front of the ankle-joint, where it divides into lateral and medial terminal branches. It lies at first on the lateral side of the anterior tibial artery, then in front of it, and again on its lateral side at the ankle-joint.

In the leg, the deep peroneal nerve supplies *muscular branches* to the tibialis anterior, extensor hallucis longus, extensor digitorum longus and peroneus tertius, and an *articular branch* to the ankle-joint.

The *lateral terminal branch* of the deep peroneal nerve passes across the tarsus, deep to the extensor digitorum brevis, and having become enlarged, like the posterior interosseous nerve at the wrist, supplies the extensor digitorum brevis. From the enlargement three minute *interosseous branches* are given off which supply the tarsal joints, and the metatarsophalangeal joints of the second, third, and fourth toes. The first of these sends a filament to the second dorsal interosseous muscle.

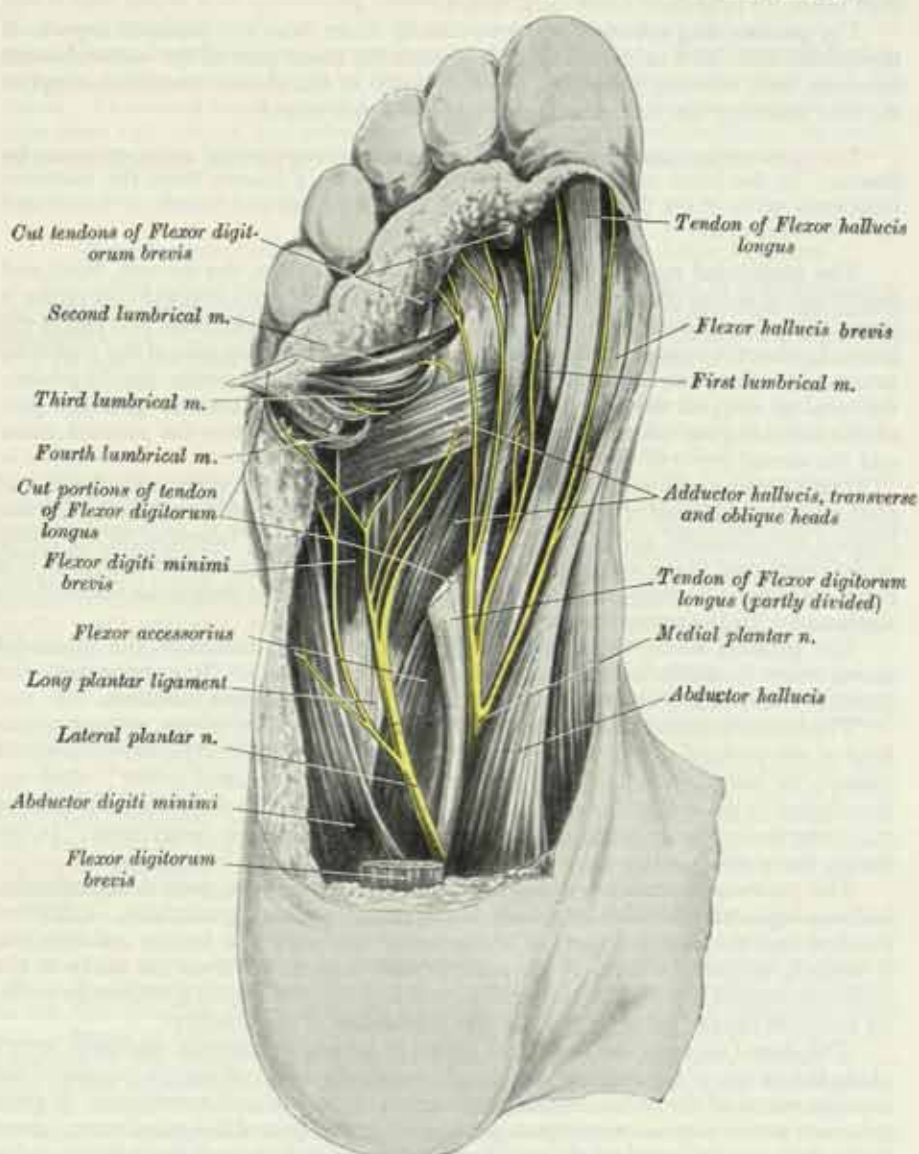
The *medial terminal branch* of the deep peroneal nerve runs forwards on the dorsum of the foot, and lies on the lateral side of the dorsalis pedis artery. At the first interosseous space it communicates with the medial branch of the superficial peroneal nerve, and divides into two dorsal digital nerves, which supply the adjacent sides of the great and second toes. Before it divides it gives off an *interosseous branch* which supplies the metatarsophalangeal joint of the great toe and sends a filament to the first dorsal interosseous muscle.

The **superficial peroneal (musculocutaneous) nerve** (fig. 976) begins at the bifurcation of the common peroneal nerve and lies at first between the peroneus

* Gardner, Ernest, *Anat. Rec.*, 101, 1948.

longus and the peroneus brevis. It then passes forwards and downwards between the peronei and the extensor digitorum longus, pierces the deep fascia at the lower one-third of the leg, and divides into a medial and a lateral branch. In its course

FIG. 986.—A dissection of the lateral and medial plantar nerves of the right foot.



Most of the flexor digitorum brevis has been removed. The flexor digitorum longus has been partially divided and its distal end has been turned forwards together with the second, third and fourth lumbrical muscles.

between the muscles, it gives off muscular branches to the peroneus longus and peroneus brevis, and filaments to the skin of the lower part of the leg.

The *medial branch* passes in front of the ankle-joint, and divides into two dorsal digital nerves, one of which supplies the medial side of the great toe, the other, the adjacent sides of the second and third toes. It communicates with the saphenous nerve and with the deep peroneal nerve (fig. 975).

The *lateral branch*, the smaller, passes along the lateral part of the dorsum of the foot, and divides into dorsal digital branches, which supply the contiguous sides of the third and fourth, and of the fourth and fifth toes. It also supplies the skin of the lateral side of the ankle, and communicates with the sural nerve (fig. 975).

The branches of the superficial peroneal nerve supply the skin of the dorsal surfaces of all the toes excepting the lateral side of the little toe and the adjoining sides of the great and second toes, the former being supplied by the sural nerve, and the latter by the medial terminal branch of the deep peroneal nerve. Frequently some of the lateral branches of the superficial peroneal are absent, and their places are then taken by branches of the sural nerve.

The **perforating cutaneous nerve** usually arises from the posterior aspects of the second and third sacral nerves. It pierces the lower part of the sacrotuberous ligament, and, winding round the inferior border of the gluteus maximus, supplies the skin covering the medial and lower parts of that muscle.

The perforating cutaneous nerve may arise from the pudendal nerve or it may be absent; in the latter case its place may be taken by a branch from the posterior cutaneous nerve of the thigh or by a branch from the third and fourth, or fourth and fifth, sacral nerves.

The **pudendal nerve** (fig. 731) derives its fibres from the second, third and fourth sacral nerves (fig. 978). Passing between the piriformis and the coccygeus, it leaves the pelvis through the lower part of the greater sciatic foramen and enters the buttock, where it crosses the spine of the ischium on the medial side of the pudendal artery. It accompanies this artery through the lesser sciatic foramen into the pudendal canal (p. 603) on the lateral wall of the ischiorectal fossa; in the posterior part of this canal it gives off the inferior rectal, and then divides into the perineal nerve and the dorsal nerve of the penis or clitoris.

The *inferior rectal nerve* occasionally arises directly from the sacral plexus; it pierces the medial wall of the pudendal canal, crosses the ischiorectal fossa with the inferior rectal vessels, and is distributed to the sphincter ani externus, to the lining of the lower part of the anal canal and to the skin round the anus. Branches of this nerve communicate with the perineal branch of the posterior cutaneous nerve of the thigh and with the scrotal nerves.

The *perineal nerve*, the inferior and larger terminal branch of the pudendal nerve, runs forwards below the internal pudendal artery. It accompanies the perineal artery and divides into scrotal (or labial) and muscular branches.

The *scrotal branches* are two, a medial and a lateral. They pierce, or pass superficial to, the perineal membrane, and run forwards along the lateral part of the urethral triangle in company with the scrotal branches of the perineal artery; they are distributed to the skin of the scrotum, and communicate with the perineal branch of the posterior cutaneous nerve of the thigh and with the inferior rectal nerve. In the female the corresponding nerves (*labial branches*) supply the labium majus.

The *muscular branches* are distributed to the transversus perinei superficialis, bulbospongiosus, ischiocavernosus, transversus perinei profundus, sphincter urethrae and the anterior parts of the external sphincter and levator ani muscles. A branch, termed the *nerve to the urethral bulb*, is given off from the nerve to the bulbocavernosus; it pierces this muscle, and supplies the corpus spongiosum penis, its terminal fibres ending in the mucous membrane of the urethra.

The *dorsal nerve of the penis* runs forwards above the internal pudendal artery along the ramus of the ischium, and accompanies the artery along the margin of the inferior ramus of the pubis, on the deep surface of the perineal membrane. It gives a branch to the corpus cavernosum penis and, at the apex of the membrane, passes through the lateral part of the gap between that structure and the inferior pubic ligament. It then runs forwards, in company with the dorsal artery of the penis, between the layers of the suspensory ligament, to the dorsum of the penis, and ends in the glans penis. In the female the corresponding nerve (*dorsal nerve of the clitoris*) is very small, and supplies the clitoris.

The **visceral branches** arise from the second, third and fourth sacral nerves, and are distributed to the pelvic viscera. They are termed the *pelvic splanchnic nerves* and are described on p. 1200.

The **muscular branches** are derived from the fourth sacral, and supply the levator ani, coccygeus and sphincter ani externus. The branches to the levator ani and coccygeus enter their pelvic surfaces; that to the sphincter ani externus (perineal branch of fourth sacral nerve) reaches the ischiorectal fossa by piercing the coccygeus or by passing between it and the levator ani. Cutaneous filaments from this branch supply the skin between the anus and the coccyx.

The coccygeal plexus.—The coccygeal plexus is formed by a small descending branch from the ventral ramus of the fourth sacral nerve, and the ventral rami of the fifth sacral and coccygeal nerves. The ventral ramus of the fifth sacral nerve emerges from the sacral hiatus and turns forwards round the lateral margin of the sacrum below the cornu. It pierces the coccygeus muscle to gain its pelvic surface and is then joined by a descending filament from the fourth sacral nerve. The small trunk so formed descends on the pelvic surface of the coccygeus and unites with the minute ventral ramus of the coccygeal nerve, which descends from the sacral hiatus, turns round the lateral margin of the coccyx and pierces the coccygeus to gain the pelvis. This small trunk constitutes the *coccygeal plexus*. The anococcygeal nerves arise from this plexus, and consist of a few fine filaments which pierce the sacrotuberous ligament and supply the skin in the region of the coccyx.

THE MORPHOLOGY OF THE SPINAL NERVES AND THE LIMB PLEXUSES

The spinal nerves which conform to the primitive arrangement in their behaviour are the nerves of those segments which have retained to a large extent their metameric characters, viz. T. 2—L. 1. These typical spinal nerves are distributed according to a very definite plan. The dorsal ramus passes backwards and downwards lateral to the articular processes and divides into a medial and a lateral branch which penetrate the deep muscles of the back. Both branches innervate the muscles amongst which they lie, and either the one or the other becomes superficial and supplies a band of skin extending from the posterior median line to the scapular line.

The ventral ramus is connected to the corresponding ganglion on the sympathetic trunk by both a white and a grey ramus communicans. After innervating the subvertebral muscles, it passes round the body wall supplying branches to the lateral muscles of the trunk, and in the neighbourhood of the midaxillary line gives off a lateral branch which pierces the overlying muscles and divides into an anterior and a posterior division for the supply of the skin. The main trunk is continued forwards in the body wall and, after supplying the ventral muscles, distributes its terminal branches to the skin.

The behaviour of the ventral rami of the spinal nerves of the segments which have lost their obvious metamerism is greatly modified, and the initial modification is seen in the manner in which adjoining nerves unite to form the cervical, brachial, lumbosacral and coccygeal plexuses.

The cervical plexus.—The cutaneous branches of this plexus are homologous with the anterior terminal and the lateral branches of the typical spinal nerves. The transverse cutaneous nerve of the neck and the anterior supraclavicular nerves represent the anterior terminal branches; the lesser occipital and the posterior supraclavicular represent the lateral branches, while the great auricular and the middle supraclavicular probably represent elements of both branches.

The brachial plexus.—In the formation of the brachial and lumbosacral plexuses the division of the constituent nerves of the plexus into anterior or ventral and posterior or dorsal branches is characteristic. In the brachial plexus the division affects the three trunks of the plexus (p. 1156) and, to a remarkable extent, it conforms to the differentiation of the primitive musculature of the limb into a ventral or flexor and a dorsal or extensor group. So far as the cutaneous innervation is concerned, branches of the ventral divisions of the trunks take a large part in the supply of the skin of the dorsal surface of the limb. This problem has been fully discussed by Wilfred Harris,* who believes that each constituent root of the plexus originally divided into ventral and dorsal branches and that, on the evolution of the human type of plexus, inherently dorsal fibres enter the ventral branches of the trunks. As a result of this rearrangement fibres of the median and ulnar nerves have a wide area of supply on the dorsal surface of the hand.

The position of the developing limb-bud on the ventrolateral aspect of the trunk and the behaviour of the first and second thoracic nerves provide considerable support for the view that the constituent nerves of the great limb-plexuses represent only the lateral branches of the typical spinal nerves. The second thoracic nerve sends its lateral cutaneous branch into the upper limb as the intercostobrachial nerve, and the size of this nerve varies inversely with the size of the direct contribution which the second thoracic nerve makes to the brachial plexus. Otherwise the second thoracic behaves like a typical spinal nerve. The first thoracic nerve sends a large contribution to the brachial plexus, and this is clearly homologous with the lateral branch. The remainder of the nerve, despite its small size, behaves in a typical manner, although its fine anterior

* Wilfred Harris, *The Morphology of the Brachial Plexus*, Oxford University Press, 1939.

cutaneous branch is often wanting, and, when present, only supplies a limited area of skin.

The lumbosacral plexus.—The division of the constituent nerves of the lumbar and sacral plexuses into anterior or ventral and posterior or dorsal divisions is not so obvious as the corresponding division in the brachial plexus, but it can be demonstrated anatomically that the obturator and the tibial nerves arise from ventral and the femoral and peroneal nerves from dorsal divisions. The lateral branches of the twelfth thoracic and first lumbar nerves are drawn down over the iliac crest to assist in the innervation of the skin of the buttock, but otherwise these nerves behave as typical spinal nerves. The second lumbar nerve behaves in a manner which renders its interpretation difficult, since it not only gives a substantial contribution to the lumbar plexus but also possesses both an anterior terminal branch, the genital branch of the genitofemoral nerve, and a lateral cutaneous offset, represented by the lateral cutaneous nerve of the thigh and the femoral branch of the genitofemoral nerve. The anterior terminal portions of the third, fourth and fifth lumbar and the first sacral nerves are suppressed, but the corresponding portions of the second and third sacral nerves supply the skin, etc., of the perineum.

THE DISTRIBUTION OF THE SPINAL NERVES TO THE SKIN OF THE TRUNK AND LIMBS

The area of skin supplied by any one spinal nerve, through both of its primary rami, constitutes a *dermatome*, and, typically, the dermatomes extend round the body from the posterior to the anterior median line (figs. 971, 989). The dermatomes of consecutive spinal nerves overlap to a considerable extent and this is seen best in those segments of the body which have been least affected by the development of the limbs, i.e. T. 2–L. 1 (fig. 987). Further, in the same dermatome the tactile elements of sensibility cover a wider area than the other elements.

In certain situations, e.g. the upper part of the anterior thoracic wall, the cutaneous nerves supplying two adjoining areas are not derived from consecutive spinal nerves and the overlap between C. 4, above, and T. 2, below, is minimal. When T. 2 is destroyed, the line of anaesthesia is sharply demarcated; although there may be some overlap of the painful and thermal elements. On the other hand the results found after section of a peripheral nerve (e.g. the ulnar nerve at the wrist) show that the area of tactile loss is always greater than the area of loss of painful and thermal sensibilities, for the degree of overlap of fibres conveying these types of sensibility is always more extensive than the overlap of fibres conveying tactile sensibility. As a result the area of total anaesthesia and analgesia following section of a peripheral nerve is considerably less than might have been anticipated from a knowledge of its anatomical distribution.*

The first cervical nerve gives off no cutaneous branches. The second cervical nerve usually distributes its cutaneous offsets to the skin of the head, from the vertex backwards to the neighbourhood of the superior nuchal line, the cranial surface and most, if not the whole, of the lateral surface of the auricle, the skin over the angle of the mandible and below the chin (fig. 940). The third cervical nerve supplies a very oblique band of skin, commencing behind over the back of the scalp and the upper part of the back of the neck and passing forwards and downwards across the side of the neck. The area increases in extent as it is traced forwards, and in the ventral median line extends from the hyoid bone down to the level of the first rib. The fourth cervical nerve supplies the upper half or more of the back of the neck, and the area widens as it is traced downwards and forwards round the side of the neck to the anterior aspect of the trunk. It supplies the skin over the clavicle and first intercostal space, as well as over the acromion and the upper part of the deltoid muscle.

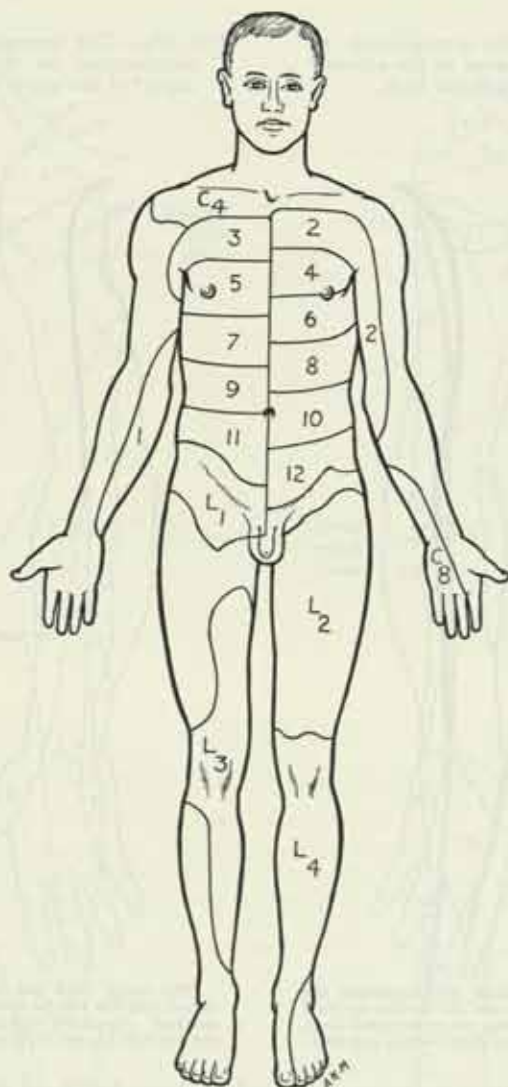
Each of these three areas is overlapped by the succeeding area, but the amount of overlapping is slight and is greater for the dorsal rami than for the ventral rami.

The cutaneous distribution of the nerves of the brachial plexus becomes intelligible only when reference is made to an early stage in the development of the upper limb. In a human embryo of the fourth week the upper limb is represented by a small, somewhat flattened elevation on the ventrolateral aspect of the trunk opposite to the lower four cervical and the first thoracic segments. The ectoderm covering it is directly continuous with the ectoderm of the trunk and draws its nerve-supply from the nerves of the corresponding segments. Similarly, its contained mesoderm is also continuous with the mesoderm of the same segments. The lower limb bud appears at a slightly later stage and always lags behind the upper limb bud in its development.

* O. Foerster, *Brain*, 56, 1933: H. H. Woollard, G. Weddell and J. A. Harpman, *J. Anat.*, 74, 1940.

The limb buds, which project from the trunk in a ventri-lateral direction, possess ventral and dorsal surfaces and cephalic or *preaxial* and caudal or *postaxial* borders. In the upper limb the *fifth cervical nerve* supplies a strip of skin on both ventral and dorsal surfaces along the preaxial border, and the *first thoracic nerve* has a similar distribution along the postaxial border. The intervening nerves supply parallel strips of skin on both the ventral and dorsal surfaces. As the limb elongates the central nerves of the plexus (C. 6, 7 and 8) become buried proximally and reach the skin only

FIG. 987.—The cutaneous areas supplied by the ventral rami of the thoracic and upper four lumbar nerves. (After Foerster.)



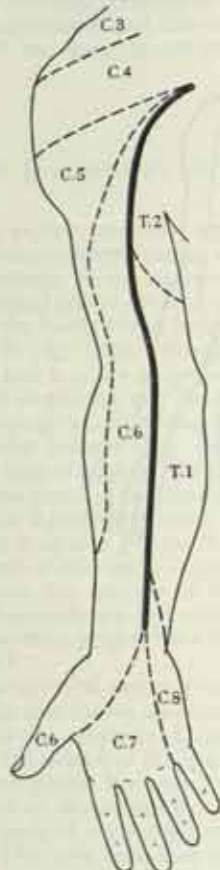
Note.—By comparing the right and left sides of the figure the degree of overlapping may be estimated, as well as the area of exclusive supply of any individual nerve.

in its more distal part, while the nerves of the adjoining segments (C. 4 and T. 2 and 3) became drawn in to supply the skin at the root of the limb. In the process of growth the lengthening upper limb becomes rotated laterally through an angle of 90° and adducted to the trunk (p. 121). In the later stages, therefore, the *preaxial border* runs distally along the lateral aspect of the limb to the thumb, which is the *preaxial digit*, while the *postaxial border* runs distally along the medial aspect to the little finger, which is the *postaxial digit*. Accordingly, the cutaneous nerve supply of the lateral aspect of the adult limb is derived from C. 4, which has been drawn in at the root of the limb, C. 5 and C. 6, and its medial aspect from T. 2, T. 1 and C. 8 (fig. 98). On the *front of the limb* the areas supplied by C. 5 and C. 6 adjoin the areas supplied by

T. 2, T. 1 and C. 8 but at the dividing line between them, which is termed the *ventral axial line*, the overlap is minimal, for C. 7 is buried proximally and only reaches the skin a little proximal to the wrist (fig. 988). On the *back of the limb* the condition is very similar, but C. 7 (in the posterior cutaneous nerve of the forearm) reaches the skin at, or a little proximal to the elbow so that the *dorsal axial line* ends at a more proximal level (fig. 989).

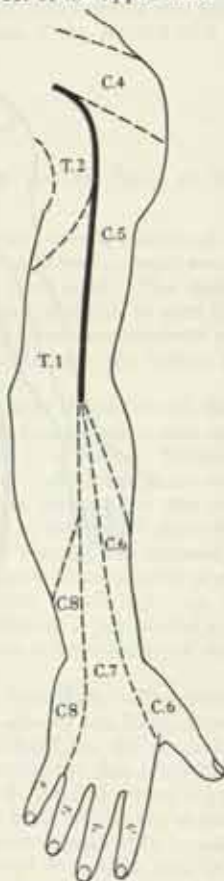
The *skin of the trunk* is supplied by the spinal nerves T. 2 to L. 1, inclusive, and by the sacral nerves, with the exception of the first, and by the coccygeal nerve. These nerves supply consecutive curved bands of skin, of which the upper are almost horizontal while the lower are disposed obliquely. The upper half of each band receives

FIG. 988.—The arrangement of the dermatomes on the anterior aspect of the upper limb.



The heavy black line represents the *ventral axial line* and the overlap across it is minimal. Across the interrupted lines, the overlap is very considerable (see text).

FIG. 989.—The arrangement of the dermatomes on the posterior aspect of the upper limb.



The heavy black line represents the *dorsal axial line* and the overlap across it is minimal. Across the interrupted lines the overlap may be, and often is considerable.

additional supply from the nerve above and the lower half from the nerve below, so that no appreciable loss of sensibility follows the section of any typical spinal nerve. It is convenient to remember that the band which includes the subcostal angle is supplied by the seventh thoracic nerve and that the umbilicus lies in the upper part of the band supplied by the tenth thoracic nerve.

The areas supplied by the dorsal rami of these nerves are limited laterally by the dorsolateral line, which commences above on the back of the head and runs downwards and laterally to the medial end of the acromion. It is then continued downwards to the posterior aspect of the greater trochanter of the femur where it curves medially to the coccyx. The cutaneous strips supplied by the dorsal rami do not correspond exactly to the strips supplied by the ventral rami, for they differ both in their breadth and in their position.

On the upper part of the anterior aspect of the thorax the third and fourth cervical areas adjoin the (first and) second thoracic areas (fig. 971), owing to the fact that the

intervening nerves have been drawn off to supply the upper limb, and a similar but less extensive gap is found on the posterior aspect of the trunk.

A corresponding arrangement is found in the lower part of the trunk, but it is not so obvious owing to the approximation of the lower limbs to one another. The first

FIG. 990.—The segmental distribution of the nerves of the lumbar and sacral plexuses to the skin of the anterior aspect of the lower limb.
See also p. 1196.

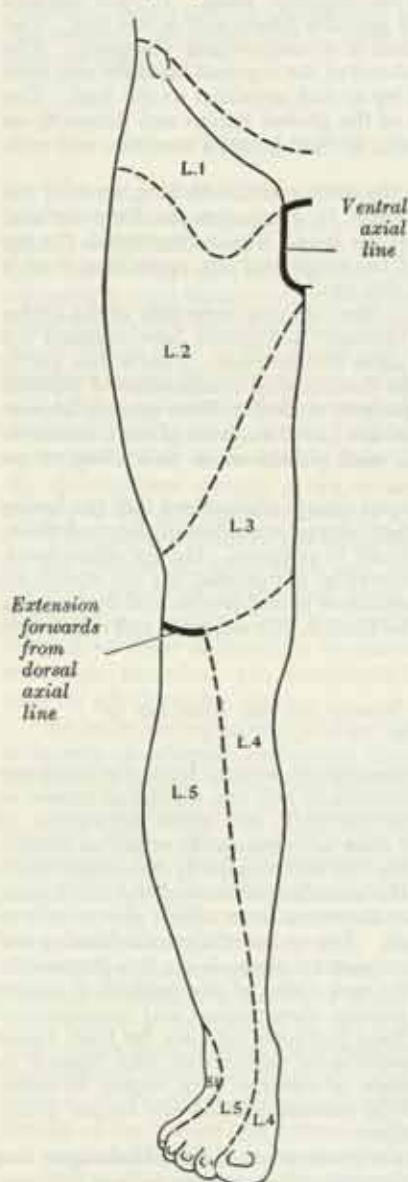
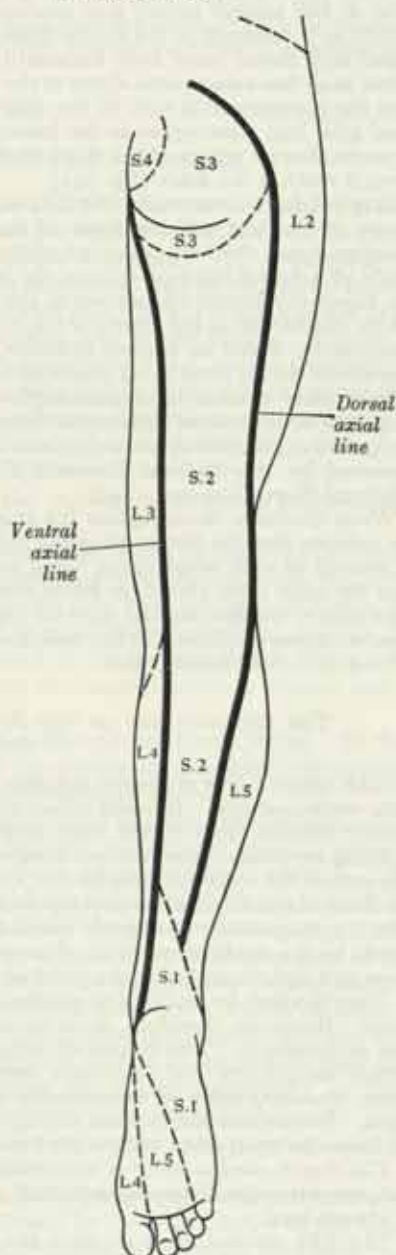


FIG. 991.—The segmental distribution of the nerves of the lumbar and sacral plexuses to the skin of the posterior aspect of the lower limb.
See also p. 1196.



lumbar area adjoins the second sacral area at the root of the penis and scrotum, for the intervening nerves have been drawn off to supply the lower limb.

The skin of the lower limb is innervated by the nerves of the segments from which it is derived, viz. T. 12-S. 3. The arrangement originally is precisely similar to the arrangement in the upper limb, but its identification in the adult has been rendered

difficult on account of the torsion of the lower limb in the early stages of its development (p. 121). Originally the *preaxial border* follows the cephalic border of the limb bud to the hallux, which is the *preaxial digit*, while the *postaxial border* follows its caudal margin to the little toe, which is the *postaxial digit*. As development proceeds, the limb undergoes torsion in a *medial* direction so that the hallux comes to lie on the medial side of the adult foot and the little toe on its lateral side. The tibia, although homologous with the radius, lies on the medial side of the leg.

The preaxial border commences above on the middle of the front of the thigh and runs down to the knee. It then curves medially as it descends to the medial malleolus to gain the medial side of the foot and the hallux. The postaxial border commences above in the gluteal region and descends to the popliteal fossa. It then inclines laterally as it descends to the lateral malleolus to gain the lateral side of the foot. The *ventral* and *dorsal axial lines* necessarily exhibit a corresponding obliquity. The ventral axial line commences above at the medial end of the inguinal ligament and runs down the posteromedial side of the thigh and leg to end proximal to the heel. The dorsal axial line commences in the lateral part of the gluteal region and descends on the posterolateral aspect of the thigh to the knee. It then inclines medially and ends before it reaches the ankle (fig. 991).

It is helpful to remember that L. 4 supplies the hallux, and with L. 5, most of the dorsum of the foot and the front of the leg, while S. 1 supplies the little toe and adjoining digits, the heel and most of the sole of the foot. S. 2 is responsible for the supply of a broad band of skin on the back of the thigh and leg, stretching from a little below the gluteal fold almost to the ankle (fig. 991).

Our knowledge of the extent of the individual dermatomes, especially of the limbs, is necessarily based on clinical evidence, and different authorities have mapped out areas which are far from being identical for the same dermatomes. This is due, partly to their failure to adopt a common method in the neurological examination of patients and partly to individual differences between patients suffering from similar lesions. The figures of the limb dermatomes here inserted are based on those of the Committee appointed by the Medical Research Council, and published in their Report on Peripheral Nerve Lesions, 1942.

When studying these figures the student must clearly understand that the *broken lines* indicate that the nerves on either side of them extend considerably beyond them, the amount of such overlapping being very difficult to estimate. On the other hand, along the *axial lines*, shown in *heavy black*, the overlap is minimal, for the nerves on either side of the line are not derived from consecutive spinal nerves and the missing nerve or nerves are buried in the substance of the limb in this situation and only reach the skin at a more distal point.

THE DISTRIBUTION OF THE SPINAL NERVES TO THE MUSCLES OF THE BODY

Each spinal nerve originally supplies the musculature derived from the myotome of the same segment. In cases where the derivatives of any one myotome persist as separate entities, they retain their original nerve-supply, but when derivatives of adjoining myotomes fuse, the resultant muscle does not necessarily retain its supply from each of the corresponding nerves, although it may and frequently does retain them all. Since the limb muscles develop *in situ* in the mesodermal core of the developing limb, it is impossible to identify the individual segments from which any muscle is derived by the study of its mode of development. The union of the individual spinal nerves and their branches in the brachial and lumbosacral plexuses renders impossible the identification by anatomical methods of the root value of the individual motor nerves. Recourse, therefore, must be had to clinical observations and experimental work on monkeys. The results obtained by these methods are very far from being entirely satisfactory and, although there is substantial agreement with regard to certain muscles, there is considerable divergence of opinion with regard to many others. In practice the student will do well if he concentrates on the former group and keeps an open mind with regard to the other.

The *fourth cervical nerve* is responsible for the innervation of the **diaphragm** and fractures or fracture dislocations above C. 4 which rupture the spinal medulla at this level are always fatal.

The *fifth cervical nerve* supplies the **abductors** and **lateral rotators** of the shoulder and the **flexors** of the elbow. It is distributed to the **deltoid** and **supraspinatus**, the **infraspinatus** and **teres minor** and to the **biceps** and **brachialis**. This distribution is reflected in the position of the upper limb after rupture of the nerve, when the shoulder is kept adducted and medially rotated and the elbow is held in extension.

The *sixth cervical nerve* supplies the **adductors** and **medial rotators** of the shoulder and the **pronator muscles**. It supplies the **pectoralis major**, the **latissimus dorsi**, the **subscapularis**, the **teres major** and the **pronator teres** muscles.

The *seventh cervical nerve* supplies the extensors of the elbow and, according to most authorities, the extensors of the wrist and digits. The muscles supplied are the **triceps**, the **extensores carpi radiales et ulnaris** and the **extensor digitorum**.

The *eighth cervical nerve* supplies the **flexores digitorum**, *superficialis et profundus*, and the **flexor carpi ulnaris**.

The *first thoracic nerve* is distributed to **all the intrinsic muscles of the hand**.

Unfortunately it is impossible to speak with the same degree of confidence about the innervation of the muscles of the lower limb. The nerve roots of the lumbar and upper sacral nerves are not commonly subjected to the same variety of tearing stresses as the nerve roots of the brachial plexus and, in consequence, there is a lack of clinical evidence. Apart from the suggestion that L.5 supplies the extensor hallucis longus and the extensor digitorum brevis, there is very little helpful information available at the present time.

THE AUTONOMIC NERVOUS SYSTEM

The autonomic nervous system comprises the splanchnic or visceral components of the nervous system (p. 917), and its fibres are distributed to the various viscera, glands and blood-vessels and to unstriated muscle in general. We have already seen that the development of a limiting sulcus in the lateral wall of the neural tube is a constant feature throughout the vertebrate series, and that as a result a motor area or basal lamina can be differentiated from a sensory area or alar lamina. Further, the nuclei which arise in the dorsal (or lateral) part of the basal lamina constitute the general visceral efferent column, while those which arise in the adjoining part of the alar lamina constitute the visceral afferent column. Certain of the constituents of the autonomic system are so intimately connected anatomically with the somatic system that they have already been dealt with, but it is necessary to repeat, in part, the descriptions already given to enable the student to obtain a comprehensive survey of the autonomic system as a whole.

The efferent fibres of the autonomic system take origin in nuclei or cell-groups in the mid-brain, hind-brain and spinal cord, and they emerge from the central nervous system as medullated fibres. They do not, however, pass direct to their distribution. Instead they are interrupted in a peripheral ganglion, and are there relayed to their destination by unmedullated or finely medullated fibres. Two neurones, therefore, are interposed between the central nervous system and the visceral effectors (fig. 992).

No such distinguishing feature marks the afferent autonomic fibres. So far as is known all afferent autonomic fibres are the peripheral branches (dendrites) of nerve-cells placed in the ganglia of the cranial or spinal nerves.

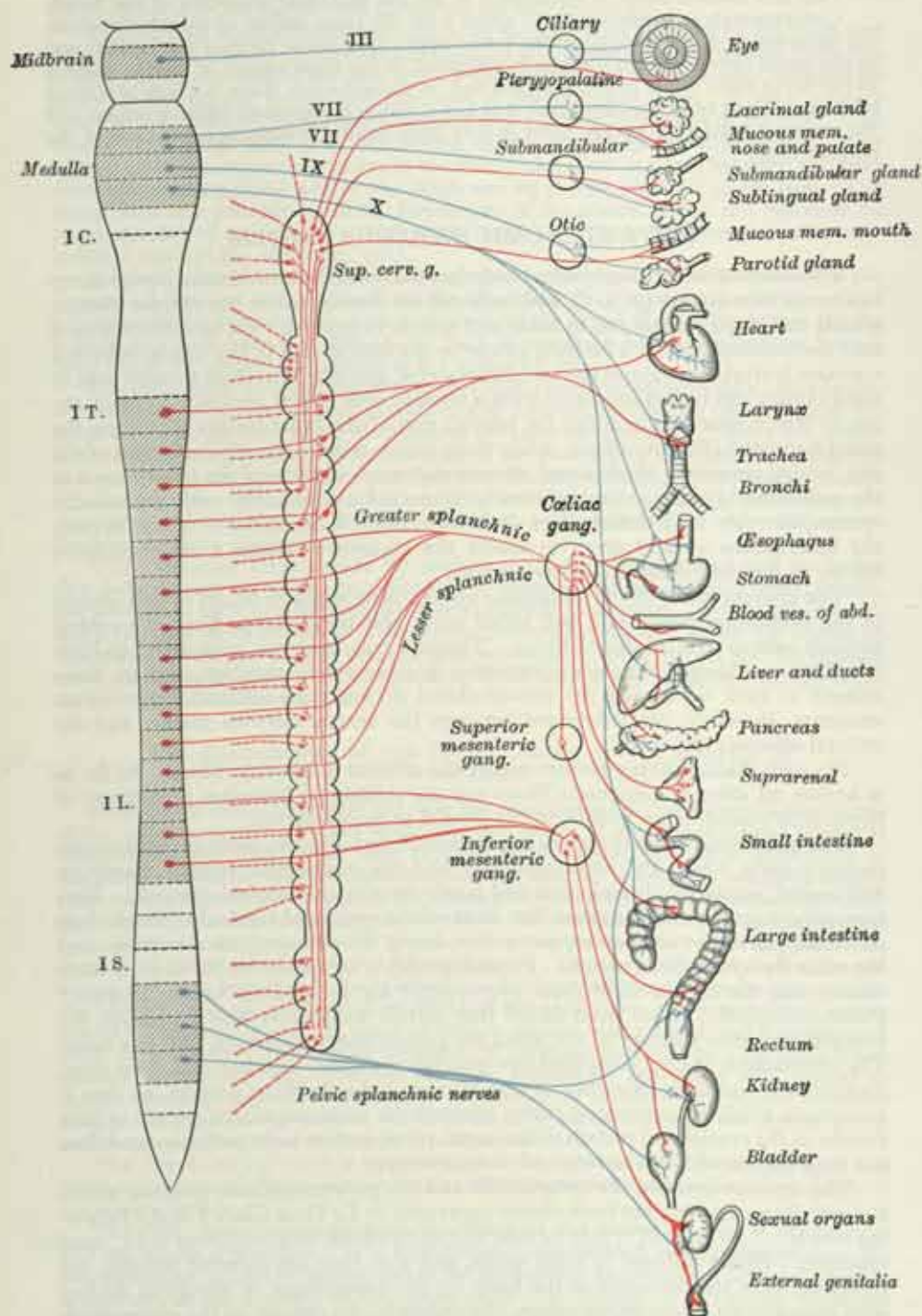
The autonomic nervous system can be subdivided into two more or less complementary parts, viz.: the *parasympathetic* and the *sympathetic systems*, partly on anatomical, partly on physiological and partly on pharmacological grounds. Anatomically it can be demonstrated that most of the viscera of the body receive their nerve-supply from two sources, one source being the parasympathetic system and the other the sympathetic system. Physiologically it can be shown for most of these viscera that the influences of these two systems are antagonistic to one another.* Pharmacologically, it has been found that certain substances which paralyse the sympathetic nerve endings do not affect the parasympathetic nerves, and *vice versa*. The sympathetic system comprises two gangliated trunks, together with their communications and their branches of distribution and subsidiary ganglia, so that it constitutes a definite anatomical entity, whereas the parasympathetic system utilises certain of the cranial and certain of the sacral spinal nerves as its pathways and does not lend itself readily for anatomical demonstration.

The contrast between the sympathetic and the parasympathetic systems, which is generally recognised, has been clearly expressed by Le Gros Clark † in the following words: "In general, it may be said that sympathetic reactions tend to be 'mass reactions', widely diffused in their effect, and that they are directed towards the mobilisation of the resources of the body for the expenditure of energy in dealing with emergencies or emotional crises. For example, the activity of the sympathetic

* For a discussion of the chemical changes involved, see Sir H. H. Dale's Croonian Lecture: "Some Chemical Factors in the Control of the Circulation," *Lancet*, 1929.

† *The Tissues of the Body*, p. 342, Clarendon Press, 1939.

FIG. 992.—A diagram of the efferent side of the autonomic nervous system. (After Meyer and Gottlieb.) The parasympathetic fibres are represented by blue, and the sympathetic fibres, by red lines; the interrupted red lines indicate post-ganglionic fibres to the cranial and spinal nerves.



system produces a vasoconstriction of cutaneous vessels leading to an increased blood-supply to the muscles, the heart and the brain, which may be called upon to accomplish additional work. Further, the heart is accelerated and the general blood-pressure raised, while other visceral activities of less immediate importance are slowed by cessation of peristalsis and closure of sphincters.

"On the other hand, the effects of parasympathetic activity are usually discrete and isolated, and are directed rather towards the conservation and restoration of resources of energy in the body. The heart is slowed, the pupils are constricted, and processes of digestion and assimilation are promoted by increased glandular secretion and enhanced visceromotor activities."

It is to be noted that, whereas the passage of a nervous impulse along a sympathetic post-ganglionic fibre is associated with the liberation of noradrenalin and adrenalin in the region of its terminals, in the cases of parasympathetic post-ganglionic fibres, all preganglionic fibres and somatic efferent fibres the substance liberated is acetylcholine. For this reason the above types of nerves are called adrenergic and cholinergic respectively. It is to be noted that the sweat glands are supplied only by postganglionic sympathetic nerves but that these are cholinergic.

THE PARASYMPATHETIC SYSTEM

Efferent pathways.—The *splanchnic efferent component* of the parasympathetic system has a limited origin from the cranial and sacral ends of the central nervous system, but has a very wide field of distribution. It is characteristic of the fibres of this system that they are all relayed in ganglia which are situated peripherally, many of them being small collections of nerve-cells lying in the walls of the viscera themselves and visible only with the aid of a microscope. Four peripheral ganglia, which, though small, are readily identifiable with the naked eye, are found in connexion with the cranial part of the parasympathetic system. They are the *ciliary* (p. 1097), the *pterygopalatine* (p. 1106), the *submandibular* (p. 1121) and the *otic* (p. 1129) ganglia, all of which have been described in detail in the section dealing with the cranial nerves. It is essential that the student should understand clearly that these ganglia are concerned solely with the outgoing parasympathetic pathway, unlike the trigeminal and facial ganglia and the ganglia of the glossopharyngeal and vagus nerves, which are all concerned with incoming impulses and contain the cells of origin of sensory fibres only. The cranial parasympathetic ganglia are traversed by afferent fibres, by postganglionic sympathetic fibres, and, in the case of the otic ganglion, even by branchial efferent fibres, but in none of these cases are the fibres interrupted during their passage through the ganglia.

The preganglionic parasympathetic fibres are medullated and are found in (1) the oculomotor, (2) the facial, (3) the glossopharyngeal, (4) the vagus and accessory nerves, and also (5) in the second and third (and fourth) sacral nerves. The post-ganglionic fibres are non-medullated and are as a rule shorter than those of the sympathetic system, as the ganglia where synapses occur are situated in or near the viscera which they supply.

(1) The oculomotor parasympathetic fibres take origin in the mid-brain, and are derived from the Edinger-Westphal nucleus (p. 1097). The preganglionic fibres travel in the nerve and leave by the branch which it supplies to the Inferior oblique muscle to enter the ciliary ganglion. There they are relayed, and the post-ganglionic fibres leave the ganglion in the short ciliary nerves, which pierce the sclera and run forwards in the perichoroidal space, to be distributed to the ciliary muscle (p. 1241) and the Sphincter pupillæ (p. 1242).

(2) The facial nerve contains efferent parasympathetic fibres which arise in the superior salivary nucleus (p. 1116) and emerge from the brain in the nervus intermedius. They travel in the facial nerve, leaving it a little above the stylomastoid foramen in the chorda tympani, which traverses the tympanic cavity and ultimately reaches the lingual nerve. In this way they are conveyed to the submandibular region, where they enter the submandibular ganglion, in which the postganglionic secretomotor fibres for the submandibular salivary gland arise (*see also* pp. 1355 and 1121). The secretomotor fibres for the sublingual gland are continued forwards in the lingual nerve after they have arisen in the submandibular ganglion (*see also* pp. 1355 and 1122). Electrical stimulation of the chorda tympani produces

dilatation of the vessels of both these salivary glands in addition to a secretomotor effect. In addition, the facial nerve probably contains efferent parasympathetic fibres which are secretomotor to the lacrimal gland. They travel by the greater petrosal nerve and the nerve of the pterygoid canal and are relayed in the pterygo-palatine ganglion. The postganglionic branches probably travel by the zygomatic nerve to reach the lacrimal gland (p. 1106) and by branches from the ganglion to glands of the nose and palate.

(3) The glossopharyngeal contains efferent parasympathetic fibres, which are secretomotor to the parotid gland. They arise in the inferior salivary nucleus (p. 1127) and travel in the glossopharyngeal nerve and its tympanic branch (fig. 948). After traversing the tympanic plexus, they enter the lesser petrosal nerve and so reach the otic ganglion. There they are relayed and the postganglionic fibres pass by communicating branches to the auriculotemporal nerve, by which they are conveyed to the parotid gland. Electrical stimulation of the lesser petrosal nerve produces a vasodilator as well as a secretomotor effect.

(4) The vagus contains a very large proportion of parasympathetic fibres. The efferent fibres arise in the dorsal nucleus of the vagus (p. 1130) and travel in the vagus nerve and in its pulmonary, cardiac, oesophageal, gastric, intestinal, etc., branches. They are all relayed in minute ganglia which lie in the walls of the individual viscera. The cardiac nerves are the nerves concerned with slowing the rate of the beat of the heart. They take part in the formation of the cardiac plexuses (p. 1215) and are then relayed in ganglia which are distributed freely over the surfaces of both atria in the sub-epicardial tissue. The terminal fibres are distributed to the atria and the atrio-ventricular bundle, and it is only through the latter structure that the vagus can exert any control over the ventricular muscle.* According to Woollard,† the smaller branches of the coronary arteries are innervated mainly by the vagus, whereas their larger branches, though possessing a double innervation, obtain their chief source of supply from the sympathetic system. The *pulmonary branches* are motor to the muscles of the bronchi, which are circularly disposed and are therefore broncho-constrictors. The synaptic relays are in the ganglia of the pulmonary plexuses. The *gastric branches* are secretomotor to the glands and motor to the muscular coats of the stomach, but they inhibit the action of the pyloric sphincter. The *intestinal branches* have a corresponding action on the small intestine, caecum, vermiform appendix, ascending colon, right colic flexure and most of the transverse colon, being secretomotor to the glands and motor to the muscular coats of the gut, but inhibitory to the ileocaecal sphincter. The synaptic relays, in this case, are situated in the myenteric (Auerbach's) plexus and the plexus of the sub-mucosa (Meissner's plexus), which are described with the structure of the intestines (p. 1432).

(5) The anterior primary rami of the second, third (and fourth) sacral nerves give off visceral branches which pass directly to the pelvic viscera. They constitute the *pelvic splanchnic nerves* (fig. 1000), and they unite with branches of the sympathetic pelvic plexuses. Minute ganglia are situated at the points of union and in the walls of the individual viscera. In these ganglia the sacral parasympathetic fibres are relayed.

The pelvic splanchnic nerves supply the rectum with visceromotor fibres, the bladder with visceromotor and its sphincter with inhibitory fibres, the erectile tissue of the penis or clitoris with vasodilator fibres, the testes or ovaries probably with vasodilator fibres, and the uterine tubes and uterus with vasodilator and possibly inhibitory fibres. In addition, filaments from the pelvic nerves pass upwards to supply the sigmoid colon, descending colon, left colic flexure and terminal part of the transverse colon with visceromotor fibres.‡ (See also pp. 1219, 1448.)

Afferent pathways.—Afferent parasympathetic pathways include the following: (1) *Visceral reflex afferent fibres* concerned in the normal reflex control of various visceral phenomena, e.g. from the lungs and heart, alimentary tract, carotid sinus, urinary bladder, etc.; (2) Fibres concerned with *organic visceral sensation*, e.g. nausea, hunger, sexual sensations, rectal distension, etc.; and (3) *Visceral pain fibres*. In general, pain fibres from the viscera pass centrally to the spinal cord in

* Cullis, W., and Tribe, E., *J. Physiol.*, **46**, 1913.

† H. H. Woollard, *J. Anat.*, **60**, 1926.

‡ E. D. Telford and J. S. B. Stopford, *British Medical Journal*, March 31, 1934: G. A. G. Mitchell, *Edin. Med. Journ.*, **42**, 1935.

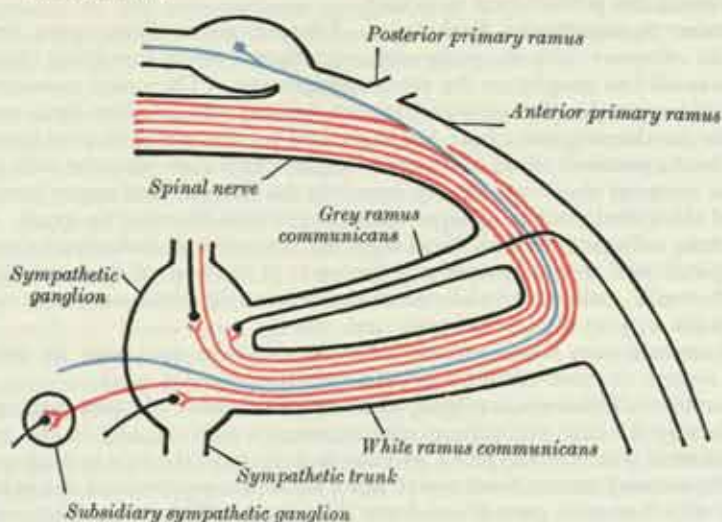
the sympathetic nerves, but in the case of some of the pelvic organs, e.g. the urinary bladder (especially the base and neck), the prostate, the prostatic urethra, the cervix of the uterus, the sigmoid colon and the rectum, pain fibres *also* pass in the pelvic splanchnic nerves. The double pathway for pain fibres from the urinary bladder, for instance, is important surgically in that operative section of the sympathetic superior hypogastric plexus alone may not be successful in the relief of bladder pain.

The afferent parasympathetic fibres mentioned above are peripheral dendrites passing from the viscera to their nerve cells of origin in the ganglia on some of the cranial nerves (glossopharyngeal, vagus) or, in the case of the pelvic nerves, in the ganglia on the posterior roots of the second, third (and fourth) sacral nerves. The axons of these cells pass into the central nervous system (medulla or sacral segments of the spinal cord) to synapse about nerve cells therein.

THE SYMPATHETIC SYSTEM

The **sympathetic nervous system**, which is the larger subdivision of the autonomic nervous system, includes the two gangliated sympathetic trunks, their branches, plexuses and subsidiary ganglia. It has a much wider distribution than

FIG. 993.—A scheme to show the destination of the preganglionic fibres of a white ramus communicans. The preganglionic fibres are shown in red and the postganglionic fibres in black. An afferent sympathetic fibre is shown in blue.



the parasympathetic system, for it innervates all the sweat glands of the skin, the erector muscles of the hairs and the muscular walls of all the blood-vessels, in addition to the heart, lungs and other viscera. The fibres which it distributes are all derived from the nerve cells in the lateral column of the grey substance of the thoracic and upper lumbar segments of the spinal cord (connector neurones) and they emerge in the anterior nerve-roots of all the thoracic and the upper two or three lumbar nerves. The limitation of this outflow from the spinal cord (the thoracolumbar outflow) is remarkable and has not been satisfactorily explained.

The ganglia on the sympathetic trunks are the first part of the system to develop and they are derived from the primitive spinal ganglia, which originate from the neural crest (p. 128). Originally, therefore, the ganglia on the sympathetic trunk correspond numerically to the ganglia on the posterior nerve-roots of the spinal nerves, but fusion of adjoining ganglia is not uncommon, and in man there are rarely more than twenty-two or twenty-three, and there may be fewer discrete ganglia. The subsidiary ganglia (e.g. the celiac ganglion, the superior mesenteric ganglion, etc.) of the sympathetic system are derivatives of the ganglia of the trunks.

Efferent pathways.—The efferent pathways from the spinal cord to the sympathetic system are always interrupted in a ganglion situated either on the sym-

pathetic trunk or in a more peripheral position. On this account the fibres of the system can conveniently be differentiated as *preganglionic* and *postganglionic fibres*. Occasionally the interruption may be in ganglia proximal to the sympathetic trunk; these are known as 'intermediate ganglia' and they are most common on the grey rami communicantes (see below) in the cervical and lower lumbar regions.* They may be of microscopic size and are sometimes situated in the anterior nerve roots or the nerve trunks. In performing surgical excision of parts of the sympathetic trunk, these intermediate ganglia would escape removal.

Two varieties of communicating branches connect the ganglia on the sympathetic trunk with the spinal nerves. These are termed *grey* and *white rami communicantes*. At least one *grey ramus communicans* connects each spinal nerve to the corresponding sympathetic ganglion. It conveys postganglionic fibres from the ganglion to the nerve for distribution to the blood-vessels, sweat glands and arrectores pilorum muscles in its area.

One *white ramus communicans* connects each of the thoracic and the first, second and, sometimes, the third lumbar nerves to the corresponding sympathetic ganglion. It conveys efferent preganglionic fibres (axons of cells in the lateral column of the grey matter) from the nerve to the sympathetic trunk and, in addition, it transmits afferent visceral fibres from the trunk to the nerve.

In addition to the white and grey rami mixed types are also found. Some of these, in the thoracic region, represent fusion of white and grey rami, but some, found only in the cervical region, contain bundles of thick myelinated fibres which are somatic efferent in character and are utilising the grey ramus as a convenient route to reach the prevertebral muscles.†

Afferent Sympathetic Pathways.—Afferent nerve fibres pass from the viscera, in company with the postganglionic efferent fibres supplying these structures, to reach the ganglia on the sympathetic trunk. They pass uninterruptedly through these ganglia (fig. 993) and thence, by way of the white rami communicantes, to the thoracic and upper lumbar spinal nerves, which convey them to the ganglia on the posterior roots of these nerves, in which their unipolar cells of origin lie. The axons of these cells finally pass into the thoracic and upper lumbar segments of the spinal cord to synapse about nerve cells therein (fig. 994). Clinical observations indicate that pain fibres from the thoracic and abdominal viscera pass to the spinal cord in the sympathetic nerves; in the case of many of the pelvic organs, however, pain fibres also run in the pelvic splanchnic nerves to the sacral segments (S. 2, 3, 4) of the cord (pp. 1200, 1201).

The visceral pain fibres probably run in the same pathways in the central nervous system as those taken by somatic pain fibres (see p. 944).

Visceral pain fibres are arranged on a segmental basis. In pathological conditions affecting a viscus the patient may experience pain vaguely in the region of the viscus itself (true visceral pain), and also in a region of the skin and other somatic tissues the sensory nerves from which enter the same segments of the spinal cord as those which receive pain fibres from the viscus. This latter phenomenon is known as *referred pain*.‡ In addition, if inflammation spreads from a diseased viscus to the *parietal* serous membrane (e.g. peritoneum) related to it, the *somatic* pain nerves will be stimulated and cause local somatic pain in this region of the body wall.

Visceral pain nerves have a higher threshold for the forms of stimulation that excite pain nerves in the skin and other somatic tissues; the adequate stimuli for visceral pain nerves include stretching (distension), strong contractions (spasms) and deprivation of blood supply (ischaemia). Thus viscera in a conscious patient can be handled, cut or burned without evoking pain, whereas, for example, stretching of the gut or of its mesentery does cause pain.

Visceral pain fibres (sympathetic or parasympathetic) probably have the same segmental connections with the spinal cord as the efferent visceral fibres, and these are indicated below, although there is diversity of opinion concerning the precise segments involved.

* J. D. Boyd and P. A. G. Munro, *Lancet*, Nov. 12, 1949, p. 892.

† Joseph Pick and Donal Sheehan, "Sympathetic Rami in Man," *J. Anat.*, 80, 1946.

‡ For an account of the theories concerning the mechanism of referred pain, see D. C. Sinclair, G. Weddell and W. H. Feindel, "Referred pain and associated phenomena", *Brain*, 71, 1948.

SEGMENTAL INNERVATION OF VISCERA

(The segments of the spinal cord mentioned below are those from which efferent preganglionic sympathetic and sacral parasympathetic fibres arise; probably the same segments also receive afferent fibres from these viscera.)

Heart.	T 1-5	Pancreas.	T 6-10
Bronchi and lungs.	T 2-5	Kidney.	T 10-L 1
Oesophagus (lower part).	T 5-6	Ureter.	T 11-L 1; S 2-4
Stomach.	T 6-10	Suprarenal.	T 10-L 1
Small intestine.	T 9-10	Testis or ovary.	T 10-11
Large intestine as far as descending colon.	T 11-L 1	Epididymis, ductus deferens and seminal vesicles.	T 11-12; S 2-4
Descending colon, sigmoid colon and rectum.	L 1-2; S 2-4	Urinary bladder.	T 11-L 2; S 2-4
Liver and gall bladder.	T 7-9	Prostate and prostatic urethra.	T 11-L 1; S 2-4
Spleen.	T 6-10	Uterus—body	T 12-L 1;
		—cervix.	S 2-4
		Uterine tube.	T 10-L 1

Structure of the sympathetic ganglia (fig. 925).—The constituent nerve-cells of the sympathetic ganglia are surrounded by a nucleated capsule, like the nerve-cells in the spinal ganglia, but unlike them they are usually multipolar. This is not surprising, for the sympathetic cells are stations on an efferent pathway and must be equipped to receive stimuli from more than one source. Examination of the Nissl's bodies has shown that their size and arrangement are sufficiently constant to justify the view that, despite differences in the behaviour and arrangement of their dendrites and axons, all these cells belong to one type.

The dendrites may pierce the capsule and ramify in the intercellular areas, but in many cases they break up within the capsule. These intracapsular plexuses may be situated on one side of the cell, constituting a *glomerulus*, and two or three neighbouring cells may participate in the formation of a glomerulus. The terminals of the preganglionic fibres break up into fine plexuses which establish synaptic relations with the extracapsular dendrites, or they may form a network which may be either pericapsular or pericellular in position.

The axons of the cells in the sympathetic ganglia are usually fine, unmyelinated fibres, but they do occasionally possess a thin sheath of myelin. They are destined either to pass directly to their distribution in one of the medial branches of the sympathetic trunk or to pass by a grey ramus communicans to join a spinal nerve, through which they are distributed. They may, however, ascend to a higher or descend to a lower level in the sympathetic trunk before leaving it. There is no evidence of the existence of any interganglionic association fibres.

The axons of the cells in the subsidiary ganglia pass directly to their distribution.

Structure of the sympathetic nerves.—The *preganglionic fibres* are all derived from the cells in the lateral column of the grey matter of the spinal cord. They are usually small in size and are myelinated. The *postganglionic fibres* are the axons of sympathetic ganglion cells. They are small in size, and, although usually unmyelinated, they may be provided with a fine, myelinated sheath. The *afferent fibres* are the peripheral branches of unipolar cells in the spinal ganglia. They vary in size, and they may or may not possess myelinated sheaths.

Mode of distribution.—The efferent fibres from the cells in the lateral column of the grey matter of the spinal cord join the anterior nerve-roots and pass into the anterior primary rami of the spinal nerves, T. 1 to L. 2 or 3. They leave the nerves, almost at once, and are conveyed by white rami communicantes to the corresponding ganglia on the sympathetic trunks or, in a few cases, synapse with ganglionic cells proximal to the trunks (see p. 1202).

The preganglionic fibres may behave in a number of different ways thereafter (fig. 993). (a) They may end in the ganglion by arborising with the dendrites of a ganglion cell; (b) they may pass through the ganglion and ascend to a ganglion at a

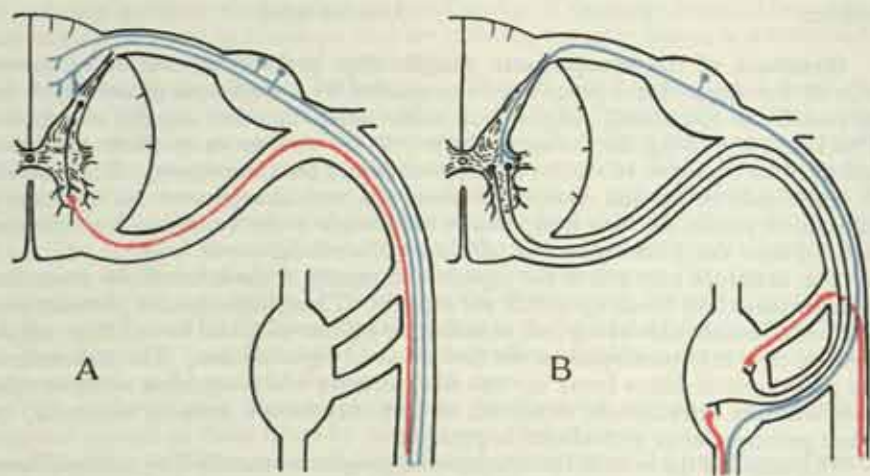
higher level or descend to one at a lower level before terminating; (c) they may pass through the ganglion without being interrupted, emerge in one of its medial branches and enter a subsidiary ganglion, where they are relayed.

The postganglionic fibres may be arranged in two groups: (a) those arising from the ganglia on the sympathetic trunks, and (b) those arising from subsidiary ganglia.

(a) Postganglionic fibres arising from a ganglion on the sympathetic trunk may reach their distribution in a variety of ways. (1) They may pass back to the corresponding spinal nerve along its grey ramus communicans. Such fibres are distributed by the anterior and posterior rami of the spinal nerve to the blood-vessels, sweat-glands, hairs, etc., in its zone of supply. (2) They may pass in a medial branch of the ganglion to be distributed to some particular viscus or viscera. (3) They may ascend to a higher level or descend to a lower level before leaving the sympathetic trunk either in one of its medial branches or in a grey ramus communicans. *Postganglionic fibres never travel in a white ramus communicans.*

(b) Postganglionic fibres arising from a subsidiary sympathetic ganglion pass direct to their distribution in one of the branches of the ganglion, although they may have to traverse a plexus *en route*.

FIG. 994.—Diagrams of the central connexions of the somatic fibres (A) and sympathetic fibres (B) of a typical spinal nerve. Afferent fibres, blue; connector neurones, black; efferent fibres, red.

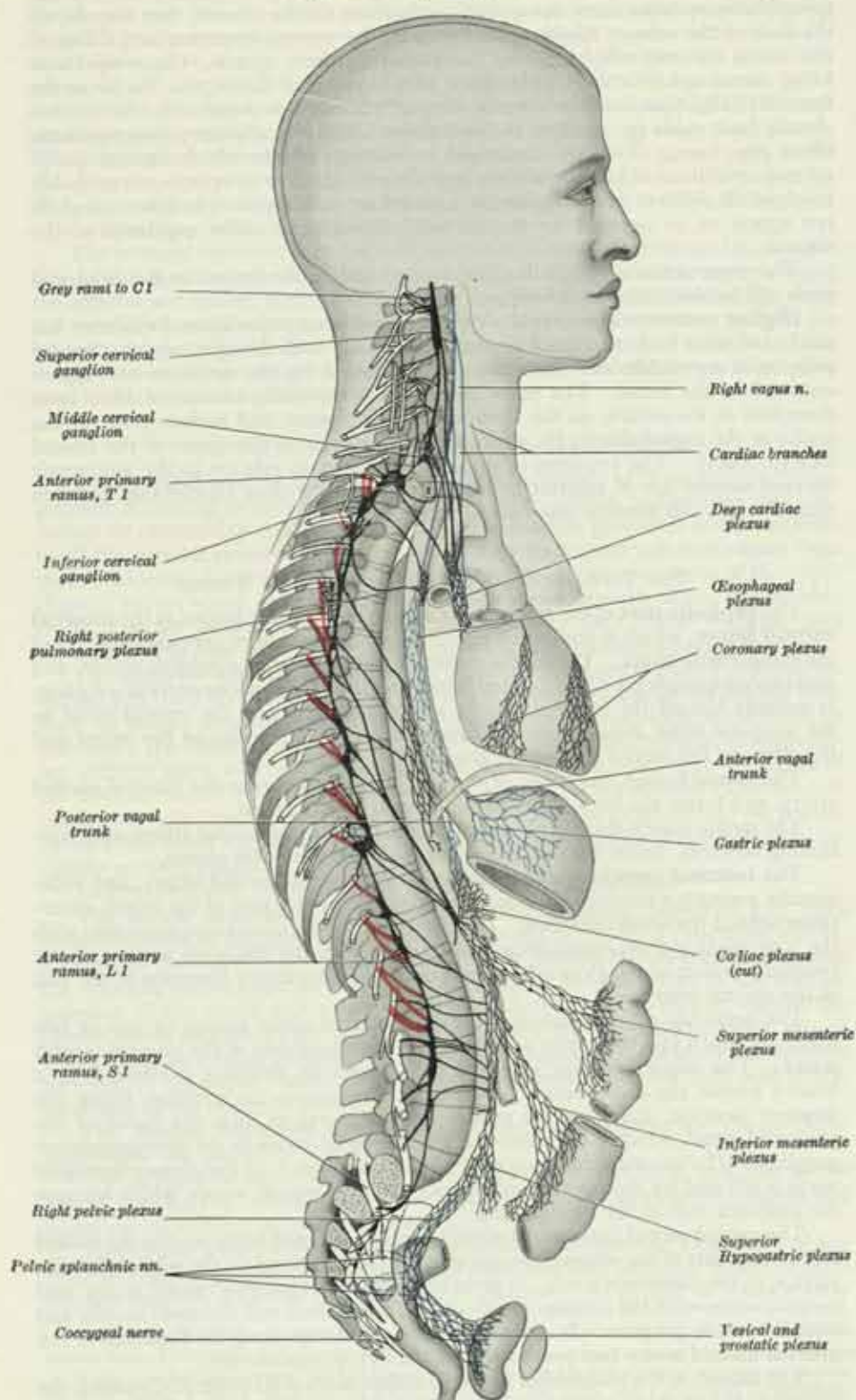


The **sympathetic trunks** are two gangliated nerve cords which extend from the base of the skull to the coccyx. In the neck the trunk is placed behind the carotid sheath and in front of the transverse processes of the cervical vertebrae; in the thorax it is placed on the heads of the ribs; in the abdomen on the anterolateral aspect of the bodies of the lumbar vertebrae; and in the pelvis, on the front of the sacrum, medial to the anterior sacral foramina. In front of the coccyx the two trunks meet each other in a terminal ganglion, termed the *ganglion impar*.

In the neck the ganglia are reduced to three in number by the fusion of adjoining ganglia, and from the upper end of the superior ganglion the internal carotid nerve takes origin. This nerve constitutes an upward continuation of the sympathetic trunk, and it accompanies the internal carotid artery through the carotid canal into the skull. In the thorax there are usually eleven ganglia, but the number may be decreased to ten or increased to twelve. There are usually four ganglia in the lumbar region, and four or five in the sacral region.

Functional Significance.—The efferent postganglionic fibres which pass in the grey rami communicantes to the spinal nerves supply vasoconstrictor fibres to the blood-vessels, secretomotor fibres to the sweat glands and motor fibres to the arrectores pilorum muscles in the areas supplied by the corresponding spinal nerve. Those which accompany the motor nerves to voluntary muscles are probably distributed only to the blood-vessels supplying the muscles. The fibres which pass to the viscera and other structures are concerned with vasoconstriction, dilatation of the pupils, dilatation of the bronchioles, glandular secretion, movements of the

FIG. 995 —The right sympathetic trunk and its connexions with the thoracic, abdominal and pelvic plexuses.



Blue = Parasympathetic fibres. Black = Sympathetic trunk and branches. Red = White rami communicantes.

alimentary tract and the urinary bladder (relaxation of the muscle walls and contraction of the sphincters), etc. While in general the sympathetic and parasympathetic systems exert antagonistic influences on the viscera they supply, in the case of the urinary bladder, for instance, the normal emptying and filling of the viscus are controlled only by the parasympathetic system, the sympathetic being concerned with the supply of the blood-vessels of the organ. So far as the functional significance of the afferent sympathetic fibres is concerned, mention has already been made (p. 1202) of the pain fibres. Whereas afferent parasympathetic fibres (pp. 1200, 1201) are concerned in visceral reflexes which operate under normal conditions of life, the afferent sympathetic fibres in most cases are probably involved in reflexes occurring under unusual or pathological conditions, and do not appear to be essential for the normal (physiological) reflex regulation of the viscera.

The innervation of the individual viscera and of structures in the head and neck will be dealt with in subsequent sections.

Higher autonomic centres.—Within recent years experimental evidence has confirmed what had, on clinical grounds, previously been thought, namely that the peripheral autonomic nervous system is influenced by the activities of 'higher centres' in the brain. The parts of the brain especially concerned have been described in the section on the Central Nervous System and include some of the nuclei in the hypothalamus (p. 1015) and certain areas of the cortex of the frontal lobe (p. 1043). The activities of the cerebral cortex in relation to the autonomic nervous system are of interest in that they indicate a close relationship between mental states and somatic and visceral activities.

THE CEPHALIC PART OF THE SYMPATHETIC SYSTEM

The **cephalic part** of the sympathetic system on each side begins as the **internal carotid nerve**, which is continued upwards from the superior cervical ganglion of the sympathetic trunk. This nerve is soft in texture, and of a reddish colour, and contains postganglionic fibres derived from the cells of the superior cervical ganglion. It ascends behind the internal carotid artery, and, entering the carotid canal in the temporal bone, divides into two branches, one of which lies on the lateral and the other on the medial side of the artery.

The *lateral branch*, the larger of the two, gives filaments to the internal carotid artery, and forms the lateral part of the *internal carotid plexus*.

The *medial branch* also supplies filaments to the internal carotid artery, and, continuing onwards, forms the medial part of the internal carotid plexus.

The **internal carotid plexus** surrounds the internal carotid artery, and occasionally presents a small gangliform swelling on the under side of the vessel, sometimes termed the *carotid ganglion*. The lateral part of the plexus communicates with the trigeminal and pterygopalatine ganglia, and with the abducent nerve and the tympanic branch of the glossopharyngeal nerve; it distributes filaments to the wall of the carotid artery.

The branches communicating with the abducent nerve consist of one or two filaments which join that nerve as it lies upon the lateral side of the internal carotid artery. The communication with the pterygopalatine ganglion is effected by a branch named the *deep petrosal*; this branch perforates the cartilage filling the foramen lacerum, and joins the greater petrosal nerve to form the nerve of the pterygoid canal, which passes through the pterygoid canal to the pterygopalatine ganglion. The communication with the tympanic branch of the glossopharyngeal nerve is effected by the *superior* and *inferior caroticotympanic nerves*, which traverse the posterior wall of the carotid canal.

The medial part of the internal carotid plexus is situated below and on the medial side of that part of the internal carotid artery which is placed by the side of the sella turcica, in the cavernous sinus. It gives branches to the internal carotid artery, and communicates with the oculomotor, trochlear, ophthalmic and abducent nerves, and with the ciliary ganglion. It also sends vasomotor twigs along the branches of the internal carotid artery that pass to supply the hypophysis cerebri.

The branch to the oculomotor nerve joins that nerve at its point of division; the branch to the trochlear nerve joins the latter as it lies in the lateral wall of the cavernous sinus; filaments are connected with the medial side of the ophthalmic nerve;

and one joins the abducent nerve. The filament to the ciliary ganglion arises from the anterior part of the plexus and enters the orbit through the superior orbital fissure; it may join the ganglion directly; it may unite with the communicating branch from the nasociliary nerve to the ganglion (p. 1097); or, it may travel via the ophthalmic nerve and its nasociliary branch. Its fibres pass through the ciliary ganglion without being interrupted and run in the short ciliary nerves to be distributed to the blood-vessels of the eyeball. The fibres which supply the Dilator pupillæ muscle usually travel by the ophthalmic, nasociliary and long ciliary nerves. The preganglionic fibres concerned leave the spinal cord in T. 1, and pass to the first thoracic sympathetic ganglion, through which they pass uninterruptedly. They then ascend in the cervical part of the sympathetic trunk to reach the superior cervical ganglion, where they are relayed.

The terminal filaments from the internal carotid plexus are prolonged as plexuses around the anterior and middle cerebral arteries and the ophthalmic artery: along the anterior and middle cerebral arteries they may be traced to the pia mater; along the ophthalmic artery they pass into the orbit where they accompany each of the branches of that vessel. The filaments prolonged on the anterior communicating artery connect the sympathetic nerves of the right and left sides and a small ganglion may be found associated with these filaments.*

THE CERVICAL PART OF THE SYMPATHETIC SYSTEM

The **cervical part** of each sympathetic trunk consists of three ganglia distinguished, according to their positions, as the superior, middle, and inferior, and connected by intervening cords (fig. 995). This part sends grey rami communicantes to all the cervical spinal nerves,† but receives no white rami communicantes from them; its spinal fibres are derived from the white rami communicantes of the upper thoracic nerves which enter the corresponding thoracic ganglia of the sympathetic trunk, through which they ascend into the neck. In their course the grey rami communicantes may pierce the Longus capitis or the Scalenus anterior muscle.

The **superior cervical ganglion**, the largest of the three, is placed opposite the second and third cervical vertebrae. It is of a reddish-grey colour and usually fusiform in shape, sometimes broad and flattened, and occasionally constricted at intervals; it is believed to be formed by the coalescence of four ganglia, corresponding with the upper four cervical nerves. It is in relation, in front, with the sheath of the internal carotid artery; behind, with the Longus capitis muscle. The internal carotid nerve (p. 1206) ascends from the upper end of the ganglion into the cranial cavity; the lower end of the ganglion is united by the connecting trunk with the middle cervical ganglion.

Its branches may be divided into lateral, medial and anterior.

The **lateral branches** of the superior cervical ganglion consist of grey rami communicantes to the upper four cervical nerves and to certain of the cranial nerves. Sometimes the branch to the fourth cervical nerve comes from the trunk connecting the superior and middle cervical ganglia. Delicate filaments run to the inferior ganglion of the vagus, and to the hypoglossal nerve; and a branch, named the *jugular nerve*, ascends to the base of the skull, and divides into two twigs, one of which joins the inferior ganglion of the glossopharyngeal, and the other the superior ganglion of the vagus; other twigs pass to the superior jugular bulb and to the meninges in the posterior cranial fossa.

The **medial branches** of the superior cervical ganglion are the laryngopharyngeal and cardiac branches.

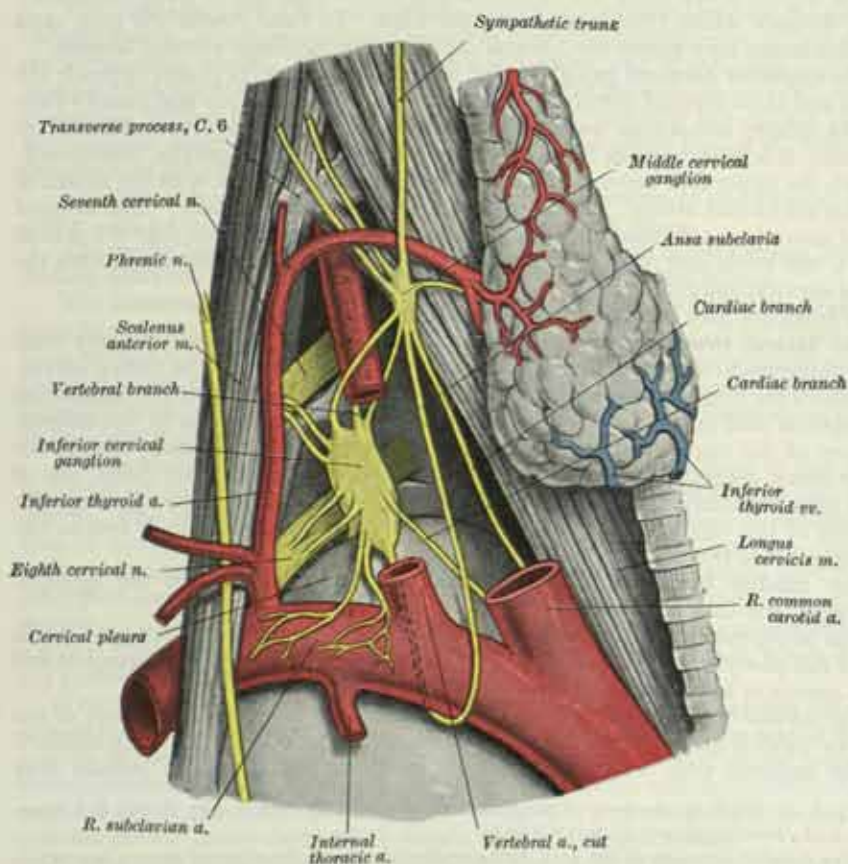
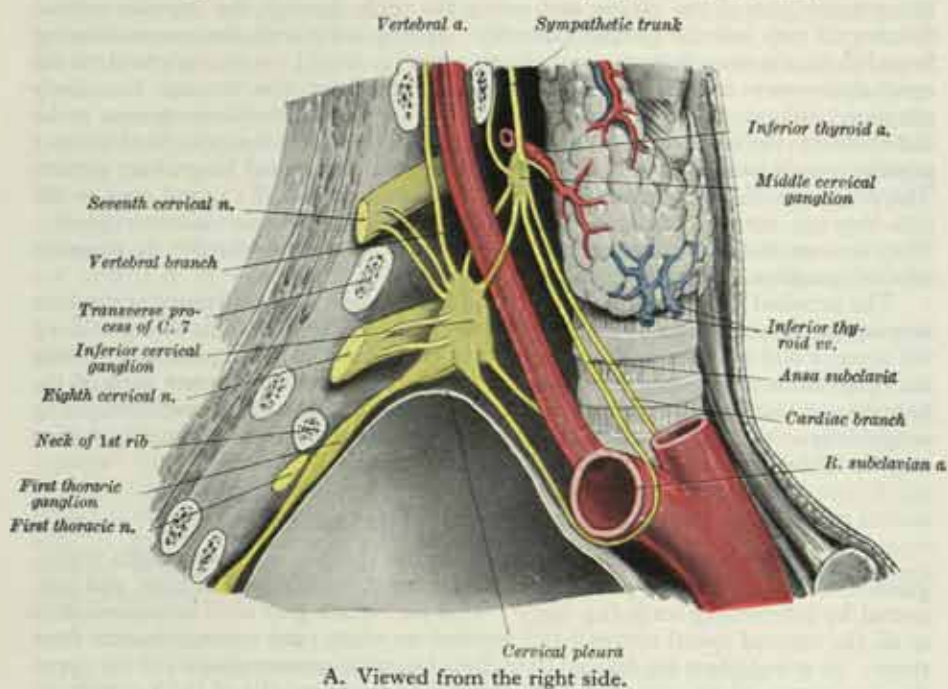
The *laryngopharyngeal branches* give twigs to the carotid body, and pass to the side of the pharynx, where they join with branches from the glossopharyngeal and vagus nerves to form the *pharyngeal plexus* (p. 1133).

The *cardiac branch* arises by two or more filaments from the lower part of the superior cervical ganglion, and occasionally receives a twig from the trunk connecting the superior with the middle cervical ganglion. It is said to contain only

* G. A. G. Mitchell, *Anatomy of the Autonomic Nervous System*, p. 207, E. and S. Livingstone, Ltd., Edinburgh and London, 1953.

† For detailed accounts of the grey rami communicantes to the cervical nerves, see papers by T. K. Potts, *J. Anat.*, 59, 1925, M. Oxford, *J. Anat.*, 62, 1928, and J. Pick and D. Sheehan, *J. Anat.*, 80, 1946, and also S. Sunderland and G. M. Bedbrook, *Brain*, Vol. 72, part 3, p. 297, 1949.

FIG. 996.—The middle and inferior cervical ganglia of the right side.



NOTE.—A portion of the vertebral artery has been excised to show the inferior cervical ganglion.

efferent fibres, the preganglionic outflow being from the upper thoracic segments of the spinal cord, and to be devoid of any visceral pain fibres from the heart (p. 1215). It runs down the neck behind the common carotid artery, and in front of the Longus cervicis muscle; it crosses in front of the inferior thyroid artery and recurrent laryngeal nerve. The course of the nerve of the right side then differs from that of the left. The *right nerve*, at the root of the neck passes, usually behind, but sometimes in front of, the subclavian artery, and posterolateral to the brachiocephalic artery to the back of the arch of the aorta, where it joins the deep part of the cardiac plexus. It is connected with other branches of the sympathetic; about the middle of the neck it receives filaments from the external laryngeal nerve; lower down, one or two cardiac branches from the vagus nerve join it; and as it enters the thorax it is joined by a filament from the recurrent laryngeal nerve. Filaments from the nerve communicate with the thyroid branches from the middle cervical ganglion. The *left nerve*, in the thorax, runs in front of the left common carotid artery and across the left side of the arch of the aorta, to the superficial part of the cardiac plexus. Sometimes it descends on the right side of the aorta and ends in the deep part of the cardiac plexus. It communicates with the cardiac branches of the middle and inferior cervical sympathetic ganglia, and sometimes with the inferior cervical cardiac branches of the left vagus, and from these mixed nerves branches pass down to form a plexus on the ascending aorta.

The **anterior branches** of the superior cervical ganglion ramify upon the common carotid artery, and upon the external carotid artery and its branches, forming around each a delicate plexus in which small ganglia are occasionally found. The plexus surrounding the facial artery supplies a filament to the submandibular ganglion, and the plexus on the middle meningeal artery sends one offset to the otic ganglion, and another, termed the *external petrosal nerve*, to the ganglion of the facial nerve.

The **middle cervical ganglion** (fig. 996), the smallest of the three cervical ganglia, is occasionally absent, being replaced by minute ganglia in the sympathetic trunk in this region. It is usually placed opposite the sixth cervical vertebra, in front of, or just above, the inferior thyroid artery, or it may lie near to the inferior cervical ganglion (*vide infra*). It is probably formed by the coalescence of two ganglia corresponding with the fifth and sixth cervical nerves.

The ganglion sends grey rami communicantes to the fifth and sixth cervical nerves, and sometimes to the fourth and seventh, and gives off thyroid and cardiac branches. It is connected to the inferior cervical ganglion by two or more cords, which are very variable in their disposition. The posterior cord usually splits to enclose the vertebral artery. The most anterior cord loops down in front of and then below the first part of the subclavian artery, medial to the origin of its internal thoracic branch, and supplies offsets to it. This loop is called the *ansa subclavia*. It is intimately related to the cervical pleura, frequently consists of more than one filament, and generally communicates with the phrenic nerve.

The *thyroid branches* run along the inferior thyroid artery to the thyroid gland; they communicate with the superior cardiac, external laryngeal and recurrent laryngeal nerves and send branches to the parathyroid glands.

The *cardiac branch*, the largest of the sympathetic cardiac branches, arises from the middle cervical ganglion, or from the trunk connecting the middle with the inferior cervical ganglion. On the *right side* it descends behind the common carotid artery, and at the root of the neck runs either in front of or behind the subclavian artery; it then descends on the trachea, receives a few filaments from the recurrent laryngeal nerve, and joins the right half of the deep part of the cardiac plexus. In the neck, it communicates with the superior cardiac and recurrent laryngeal nerves. On the *left side*, the nerve enters the thorax between the left carotid and subclavian arteries, and joins the left half of the deep part of the cardiac plexus.

Fine branches from the middle cervical ganglion also pass to the trachea and œsophagus.

The **inferior cervical ganglion** (fig. 996) lies between the base of the transverse process of the seventh cervical vertebra and the neck of the first rib, in front of the anterior ramus of the eighth cervical nerve, and immediately behind the vertebral artery and its associated veins. It is larger than the middle cervical ganglion and is probably formed by the coalescence of two ganglia corresponding with the seventh and eighth cervical nerves. In most cases the inferior cervical

and first thoracic ganglia are fused to form the *cervicothoracic ganglion* or *stellate ganglion*, so called because of its radiating branches; sometimes the second thoracic ganglion is also fused with this ganglionic mass. In cases where the middle cervical ganglion is small, or replaced by minute ganglia (*see above*), a small ganglion (the vertebral ganglion *) lies just in front of the inferior ganglion, the vertebral artery being embraced by connexions between the two ganglia. The ansa subclavia may sometimes originate from the vertebral ganglion instead of the middle cervical ganglion. The stellate ganglion lies on or just beyond the lateral border of the Longus cervicis muscle and has the superior intercostal artery immediately on its lateral side; it is separated from the posterior aspect of the cervical pleura by the suprapleural membrane.

The inferior cervical ganglion sends grey rami communicantes to the seventh and eighth cervical nerves, gives off a cardiac branch, supplies branches to neighbouring vessels, and not infrequently sends a branch to join the vagus nerve.

The grey rami communicantes to the seventh cervical nerve vary from one to five in number. Two, which is the usual number, are shown in fig. 996. Another often ascends medial to the vertebral artery and in front of the transverse process of the seventh cervical vertebra and, after communicating here with the seventh cervical nerve, sends a small branch upwards through the foramen transversarium of the sixth cervical vertebra in company with the vertebral vessels which joins the sixth cervical nerve as it emerges from the intervertebral foramen. Another inconstant branch may pass through the foramen transversarium of the seventh vertebra.

The grey rami to the eighth cervical nerve are also multiple and vary from three to six in number.

The *cardiac branch* arises from either the inferior cervical or the first thoracic ganglion. It descends behind the subclavian artery and along the front of the trachea, to join the deep part of the cardiac plexus. Behind the subclavian artery it communicates with the recurrent laryngeal nerve and the cardiac branch of the middle cervical ganglion. It is often replaced by a variable number of fine branches derived from the inferior ganglion and the ansa subclavia.

The *offsets to blood-vessels* form plexuses on the subclavian artery and its branches. The plexus on the vertebral artery is derived mainly from a stout branch of the inferior cervical ganglion which ascends behind the vertebral artery to the foramen transversarium of the sixth cervical vertebra, reinforced by branches from the vertebral ganglion or the cervical sympathetic trunk which pass upwards on the front of the artery. From the plexus, branches (deep rami communicantes) pass to the anterior rami of the upper five or six cervical spinal nerves. The plexus contains a number of nerve cells. The plexus is continued into the skull along the vertebral and basilar arteries and their branches as far as the posterior cerebral artery, where it meets the plexus derived from that on the internal carotid artery. The plexus on the inferior thyroid artery accompanies the artery to the thyroid gland, and communicates with the recurrent and external laryngeal nerves, with the cardiac branch of the superior cervical ganglion, and with the plexus on the common carotid artery. The axillary and the brachial arteries and their branches are not supplied by the subclavian plexus but by the branches of the brachial plexus, and especially by the median nerve. The fibres concerned arise in the inferior cervical ganglion and pass to the plexus along the grey rami communicantes. They travel for the most part in the lower trunk of the brachial plexus.

The preganglionic fibres concerned with supplying the upper limb are derived from the upper thoracic segments of the spinal cord, probably T2-6 (or 7). These fibres pass up the sympathetic trunk to synapse about cells mainly in the inferior cervical ganglion, whence postganglionic fibres pass to the brachial plexus, mainly the lower trunk. Most of the vasoconstrictor fibres supplying the arteries of the upper limb emerge from the spinal cord in the anterior roots of the second and third thoracic nerves. These arteries can thus be denervated surgically by cutting the sympathetic trunk below the third thoracic ganglion, severing the rami communicantes connected with the second and third thoracic ganglia, and cutting (intradurally) the anterior roots of the second and third thoracic spinal nerves. The white ramus to the first thoracic ganglion is not cut, partly because it does not convey many vasomotor or sudomotor fibres to the upper limb, but mainly because

* This is the *ganglion intermédiaire* of French anatomists.

it contains most of the preganglionic fibres which pass up the sympathetic trunk to the superior cervical ganglion, from which postganglionic branches pass to supply vasoconstrictor and sudomotor nerves to the face and neck, secretory fibres to the salivary glands, the Dilator pupillæ muscle and the involuntary muscle in the upper eyelid. Destruction of this nerve would result in constriction of the pupil, drooping of the upper eyelid (ptosis) and absence of sweating on the face and neck (Horner's syndrome).

The preganglionic fibres for the head and neck leave the spinal cord through the upper five thoracic nerves (mainly the upper three); they pass up the sympathetic trunk to synapse about cells in the cervical ganglia, whence postganglionic fibres pass to be distributed as indicated above.

The plexus around the subclavian artery, derived from the stellate ganglion and ansa subclavia, does not extend beyond the first part of the axillary artery. Beyond this, the blood vessels of the upper limb receive their sympathetic nerve supply by means of branches from the brachial plexus through nerves adjacent to the arteries, e.g. the median nerve supplies branches to the brachial artery and palmar arches, the ulnar nerve supplies the ulnar artery and palmar arches and the radial nerve supplies the radial artery.

The first and second (and sometimes the third) intercostal nerves are sometimes connected together in front of the necks of the ribs by filaments which contain postganglionic fibres derived from the grey rami associated with these nerves; these fibres provide another pathway by which postganglionic nerves from the upper thoracic ganglia may pass to the brachial plexus.*

THE THORACIC PART OF THE SYMPATHETIC SYSTEM (figs. 995, 997)

The **thoracic part** of each sympathetic trunk contains a series of ganglia, which usually correspond in number to that of the thoracic spinal nerves; but, as the first may be fused with the inferior cervical ganglion and the last may be fused with the first lumbar ganglion, and two or more of the others may coalesce, their number is variable. The thoracic ganglia, with the exception of the last two or three, rest against the heads of the ribs, and are covered by the costal pleura; the last two or three are placed on the sides of the bodies of the corresponding vertebræ. Inferiorly, the thoracic sympathetic trunk passes beneath the medial arcuate ligament (or it may pierce the crus of the diaphragm) to become continuous with the lumbar sympathetic trunk. The ganglia are small, and of a greyish colour, and are connected together by the intervening portions of the trunk. The first is larger than the others, and of an elongated form; it is frequently blended with the inferior cervical ganglion.

Two rami communicantes, a white and a grey, connect each ganglion with its corresponding spinal nerve, the white ramus joining the spinal nerve farther distally than the grey ramus (figs. 993, 994). Sometimes a grey and white ramus may be fused to form a single 'mixed' ramus.

The *medial branches from the upper five ganglia* are very small; they supply filaments to the thoracic aorta and its branches. On the aorta they form a delicate plexus (*plexus aorticus thoracalis*) together with filaments from the greater splanchnic nerve. Twigs from the second, third, and fourth ganglia enter the posterior pulmonary plexus; others, from the second, third, fourth and fifth ganglia, pass to the deep cardiac plexus.† Small branches from these pulmonary and cardiac nerves pass to the œsophagus and trachea.

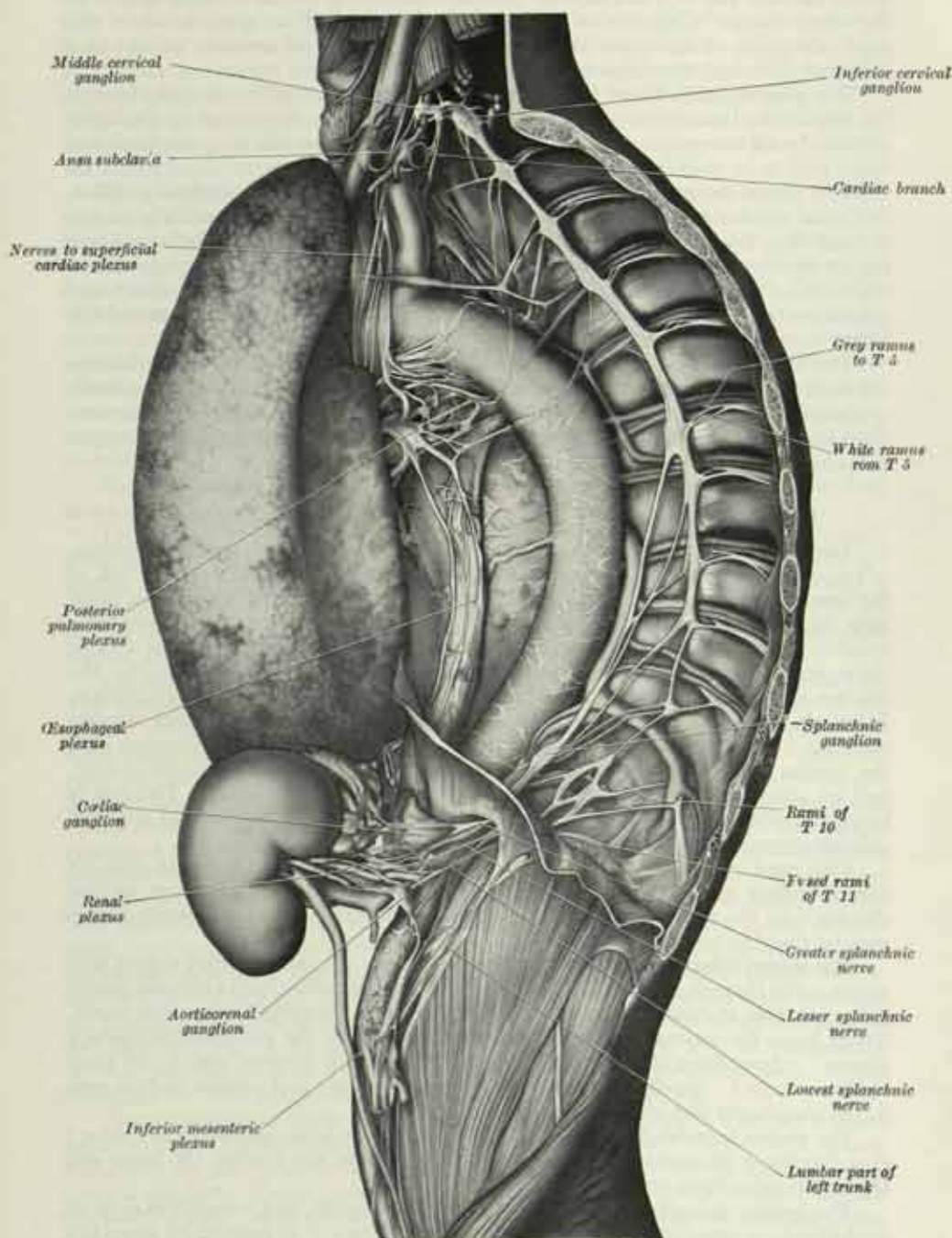
The *medial branches from the lower seven ganglia* are large, and white in colour; they distribute filaments to the aorta, and unite to form the greater, the lesser and the lowest splanchnic nerves.

The *greater splanchnic nerve* is of a considerable size, and consists mainly of medullated, preganglionic and visceral afferent fibres; it is formed by branches from the fifth to the ninth or tenth thoracic ganglia, but the fibres in the higher branches may be traced upwards in the sympathetic trunk as far as the first or second thoracic ganglion. It descends obliquely on the bodies of the vertebræ, perforates the crus of the diaphragm, and ends mainly in the celiac ganglion, but partly in the aorticorenal ganglion and the suprarenal gland. A ganglion [ganglion

* A. Kuntz, *The autonomic nervous system*, Baillière, Tindall and Cox; London, 1947.

† Ionescu, D., and Enăchescu, M., *Zeitschr. f. Anat. und Entw.* Bd. 85, 1928.

FIG. 997.—The thoracic part of the sympathetic system of the left side. (Drawn from a dissection by the late Dr. G. D. Channell.)



Note.—The diaphragm has been divided close to its origin, and the left lung and the left kidney have been drawn forwards and rotated to the right, so as to expose the posterior surface of the left kidney and suprarenal gland.

splanchnicum] exists on this nerve opposite the eleventh or twelfth thoracic vertebra.

The *lesser splanchnic nerve* is formed by filaments from the ninth and tenth, sometimes the tenth and eleventh, thoracic ganglia, and from the trunk between the ganglia. It pierces the diaphragm with the preceding nerve, and joins the aorticorenal ganglion.

The *lowest splanchnic nerve* (or *renal nerve*) arises from the last thoracic ganglion. It gains the abdomen with the sympathetic trunk, and ends in the renal plexus.

THE LUMBAR PART OF THE SYMPATHETIC SYSTEM (figs. 997, 998)

The **lumbar part** of each sympathetic trunk is situated in the extraperitoneal connective tissue in front of the vertebral column, along the medial margin of the Psoas major. It consists usually of four lumbar ganglia, connected together by the intervening portions of the trunk. It is continuous above with the thoracic portion, deep to the medial arcuate ligament; below with the pelvic portion, behind the common iliac artery.

The first and second, and sometimes the third, lumbar nerves send *white rami communicantes* to the corresponding ganglia.

Grey rami communicantes pass from all the ganglia to the lumbar spinal nerves. These rami are of considerable length and accompany the lumbar arteries round the sides of the bodies of the vertebrae, deep to the fibrous arches that give origin to the Psoas major.

Lumbar splanchnic nerves. Generally four visceral nerves pass from the ganglia to join the celiac, intermesenteric (abdominal aortic) and superior hypogastric plexuses. The first lumbar splanchnic nerve arises from the first ganglion and joins the celiac, renal and intermesenteric plexuses. The second nerve arises from the second (and sometimes also the third) ganglion and joins the lower part of the intermesenteric plexus. The third nerve arises from the third or fourth ganglion and passes in front of the common iliac vessels to join the superior hypogastric plexus. The fourth nerve arises from the lowest ganglion and passes behind the common iliac vessels to join the lower part of the superior hypogastric plexus or the hypogastric nerve.

Vascular branches. Branches from all the lumbar ganglia pass to the intermesenteric (aortic) plexus. From the lower lumbar splanchnic nerves, fibres pass to the common iliac arteries around which they form a plexus which is continued along the internal iliac artery and around the external iliac artery, in the latter case as far as the proximal part of the femoral artery. Many of the postganglionic fibres in the grey rami connecting the lumbar ganglia to the lumbar spinal nerves travel in the femoral nerve, and thence in its muscular, cutaneous and saphenous branches, to supply vasoconstrictor nerves to the femoral artery and its branches in the thigh. Other postganglionic fibres travel in the obturator nerve to the obturator artery.

THE PELVIC PART OF THE SYMPATHETIC SYSTEM (fig. 998)

The **pelvic part** of each sympathetic trunk is situated in the retroperitoneal tissue in front of the sacrum, medial to, or overlapping, the anterior sacral foramina. It comprises four or five small sacral ganglia, connected by the intervening portions of the trunk. It is continuous above with the lumbar part, while below, the two pelvic sympathetic trunks converge, and unite on the front of the coccyx in a small ganglion, which is named the *ganglion impar*.

Grey rami communicantes pass from the ganglia to the sacral and coccygeal nerves. No white rami communicantes pass to this part of the sympathetic trunk.

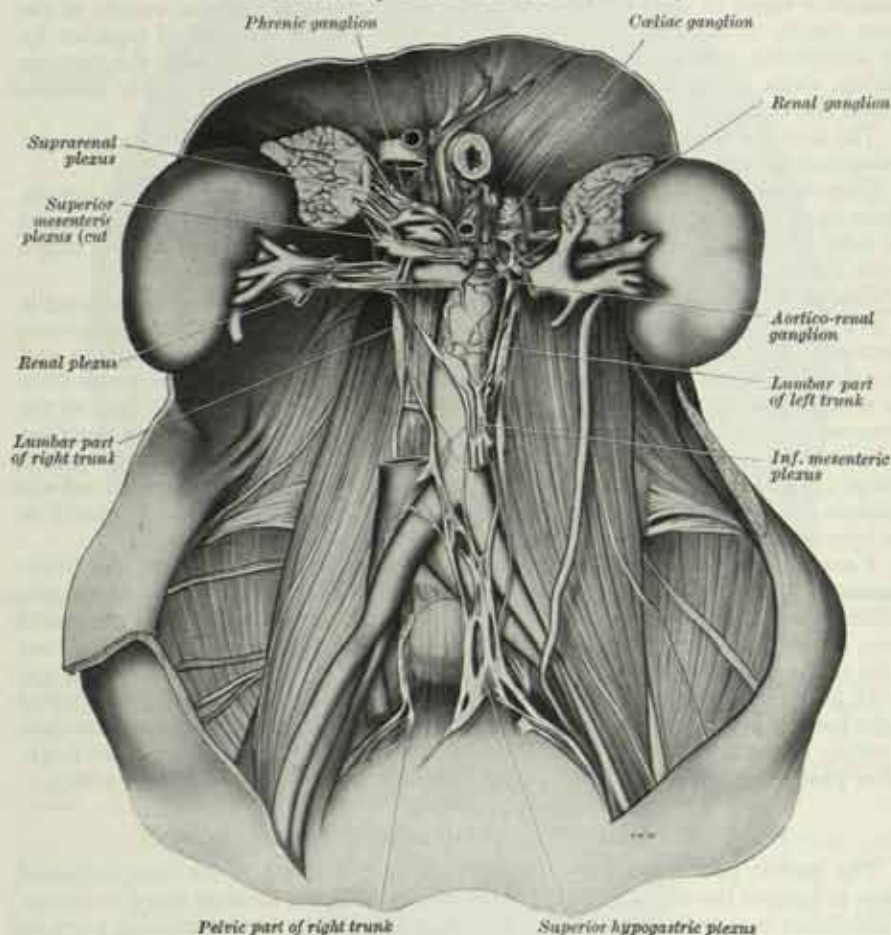
The *medial branches of distribution* communicate on the front of the sacrum with the corresponding branches from the opposite side; twigs from the first two ganglia join the inferior hypogastric plexus (pelvic plexus) or the hypogastric nerve, and others form a plexus on the median sacral artery. Filaments are distributed to the glomus coccygeum from the loop uniting the two trunks.

Vascular branches. Through the grey rami many postganglionic fibres pass to the roots of the sacral plexus, particularly those forming the tibial nerve, to be conveyed to the popliteal artery and its branches in the leg and foot. Others are conveyed by the internal pudendal and superior and inferior gluteal nerves to the accompanying arteries.

The preganglionic fibres concerned with supplying the lower limb are derived

from the lower three thoracic and upper two or three lumbar segments of the spinal cord. They reach the lower thoracic and upper lumbar ganglia through the white rami and some pass down the sympathetic trunk to synapse about cells in the lumbar ganglia, whence postganglionic fibres pass to the femoral nerve to be distributed to the femoral artery and its branches in the thigh, whereas others pass down the sympathetic trunk to synapse about cells in the upper two or three sacral ganglia, whence postganglionic fibres pass to the tibial nerve to supply the popliteal artery and its branches in the leg and foot. Sympathetic denervation of the vessels

FIG. 998.—The abdominal portion of the sympathetic system. (Drawn from a dissection by the late Dr. G. D. Channell.)



of the lower limb can thus be produced by removing the upper three lumbar ganglia and the intervening parts of the sympathetic trunk, all the preganglionic fibres to the lower limb thus being divided.

THE GREAT PLEXUSES OF THE SYMPATHETIC

The great plexuses of the sympathetic are aggregations of nerves and ganglia, situated in the thoracic, abdominal and pelvic cavities, and named the cardiac, celiac and hypogastric plexuses. From the plexuses branches are given to the thoracic, abdominal and pelvic viscera.

THE CARDIAC PLEXUS (figs. 995, 997)

The **cardiac plexus** is situated at the base of the heart, and is divided into a *superficial* and a *deep part*, which are, however, closely connected. Several small

ganglia are found in the plexus, the largest and most constant being the *cardiac ganglion* described below.

The **superficial part of the cardiac plexus** lies below the arch of the aorta, in front of the right pulmonary artery. It is formed by the cardiac branch of the superior cervical ganglion of the left sympathetic trunk, and the lower of the two cervical cardiac branches of the left vagus. A small ganglion, termed the *cardiac ganglion*, is usually present in this plexus, and is situated immediately below the arch of the aorta, on the right side of the ligamentum arteriosum. The superficial part of the cardiac plexus gives branches (*a*) to the deep part of the plexus; (*b*) to the right coronary plexus; and (*c*) to the left anterior pulmonary plexus.

The **deep part of the cardiac plexus** is situated in front of the bifurcation of the trachea, above the point of division of the pulmonary trunk, and behind the aortic arch. It is formed by the cardiac nerves derived from the cervical and upper thoracic ganglia of the sympathetic trunk, and the cardiac branches of the vagus and recurrent laryngeal nerves. The only cardiac nerves which do not join the deep part of the cardiac plexus are those which pass to the superficial part of the plexus.

The branches from the *right half* of the deep part of the cardiac plexus pass, some in front of, and others behind, the right pulmonary artery; the former, the more numerous, transmit a few filaments to the right anterior pulmonary plexus, and are then continued onwards to form part of the right coronary plexus; those behind the pulmonary artery distribute a few filaments to the right atrium, and are then continued onwards to form part of the left coronary plexus.

The *left half* of the deep part of the cardiac plexus is connected with the superficial part of the plexus, and gives filaments to the left atrium, and to the left anterior pulmonary plexus, and is then continued to form the greater part of the left coronary plexus.

The **left coronary plexus** is larger than the right, and accompanies the left coronary artery; it is formed chiefly by filaments prolonged from the left half of the deep part of the cardiac plexus, and by a few from the right half. It gives branches to the left atrium and ventricle.

The **right coronary plexus** is formed partly from the superficial and partly from the deep parts of the cardiac plexus. It accompanies the right coronary artery, and gives branches to the right atrium and ventricle.

All the cardiac branches of the vagus and the sympathetic contain both afferent and efferent fibres, except the cardiac branch of the superior cervical sympathetic ganglion which contains efferent (postganglionic) fibres only.

The *efferent* (preganglionic) sympathetic fibres arise in the upper four or five thoracic segments of the spinal cord; they pass by white rami communicantes to synapse about cells in the upper thoracic ganglia on the sympathetic trunk, though many travel up the trunk to synapse in the cervical ganglia. From the thoracic and cervical ganglia, postganglionic fibres emerge to form the sympathetic cardiac nerves, the functions of which are acceleration of the heart and dilatation of the coronary arteries. The fibres arising from the uppermost thoracic segments of the cord are distributed to the ascending aorta, the pulmonary trunk and the ventricles, while those from the lowermost segments supply the atria.

The *afferent* pain fibres from the heart run in the cardiac branches of the middle and inferior cervical sympathetic ganglia and in the thoracic cardiac nerves to reach their cells of origin in the ganglia on the posterior roots of the upper four or five thoracic spinal nerves. No pain fibres run in the cardiac branch of the superior cervical sympathetic ganglion. In the surgical treatment of severe angina pectoris, the inferior cervical and upper four or five thoracic ganglia, or the upper four or five ganglia on the posterior roots of the thoracic spinal nerves, are removed. Even after removal of these pain fibres, pain in some cases may still be felt in the region of the angle of the jaw and a dull sense of oppression may persist in the chest behind the upper part of the sternum; it is believed that the afferent fibres involved in these cases travel in the vagus.

The *efferent* parasympathetic fibres are derived from the dorsal nucleus of the vagus and from cells near the nucleus ambiguus, and run in the cardiac branches of the vagus to synapse about cells in the cardiac plexuses and in the walls of the atria. These vagal nerves are concerned with slowing of the heart and with constriction of the coronary arteries (see also p. 1200). In man (and most mammals) the intrinsic cardiac nerve cells are limited to the atria and the interatrial septum;

they are most numerous in the subepicardial connective tissue and near the sino-atrial and atrioventricular nodes.

The *afferent* parasympathetic fibres run in the cardiac branches of the vagus to their cells of origin in the inferior ganglion of the vagus. These nerves are concerned with reflexes depressing cardiac activity. In some animals (e.g. rabbit) a separate depressor cardiac nerve is present as a branch of the vagus or of the superior laryngeal nerve. In man, the depressor fibres do not form a separate nerve but run in branches of the superior or internal laryngeal nerve which join, in a variable manner, cardiac branches of the vagus or sympathetic.

The **pulmonary plexuses** lie on the anterior and posterior aspects of the bronchial and vascular structures in the roots of the lungs, the anterior pulmonary plexus being much smaller than the posterior. The plexuses are formed by branches from the vagus and the sympathetic, and both (parasympathetic and sympathetic) contain efferent and afferent fibres. The efferent parasympathetic fibres arise from the dorsal nucleus of the vagus, while the afferent fibres have their cells of origin in the inferior vagal ganglion. The efferent sympathetic fibres are postganglionic branches of the second to the fifth thoracic ganglia on the sympathetic trunk, while the afferent fibres have their cells of origin in the ganglia on the posterior roots of the second to the fifth thoracic spinal nerves.

The anterior pulmonary plexus is formed by branches from the vagus and from the deep cardiac plexus, the left anterior plexus receiving additional fibres from the superficial cardiac plexus. The posterior pulmonary plexus is formed by branches from the vagus, from the deep cardiac plexus and from the second to the fifth thoracic sympathetic ganglia, the left posterior plexus receiving additional branches from the left recurrent laryngeal nerve.

From the plexuses, nerves pass into the lung around the branches of the bronchi and pulmonary arteries, extending as far as the visceral pleura. On these nerves, near the roots of the lungs, there are minute collections of nerve cells about which the efferent preganglionic vagal fibres synapse. The efferent vagal fibres are bronchoconstrictor, secretomotor to the mucous bronchial glands and vasodilator in function, and the afferent vagal fibres are concerned in the cough-reflex and in the Hering-Breuer reflex induced by stretching of the lung in inspiration. The efferent sympathetic fibres are bronchodilator and vasoconstrictor, while the afferent fibres are concerned with the sensory innervation of the visceral pleura and the air passages.

THE COELIAC PLEXUS (figs. 995, 998)

The **cœliac** or **solar plexus**, the largest of the three great sympathetic plexuses, is situated at the level of the last thoracic and the upper part of the first lumbar vertebra, and is composed of a dense network of nerve-fibres which unite together two large ganglia, termed the cœliac ganglia. It surrounds the cœliac artery and the root of the superior mesenteric artery. It lies behind the stomach and the omental bursa, in front of the crura of the diaphragm and the commencement of the abdominal aorta, and between the suprarenal glands. The plexus and the ganglia receive the greater and lesser splanchnic nerves of both sides and some filaments from the vagus and phrenic nerves, and give off numerous secondary plexuses along the neighbouring arteries.

The *cœliac ganglia* are two large irregularly shaped masses, not unlike lymph nodes in appearance, placed, one on each side of the median plane, between the suprarenal gland and the origin of the cœliac artery, and in front of the crura of the diaphragm, that on the right side being placed behind the inferior vena cava and that of the left side behind the splenic vessels. The upper part of each ganglion is joined by the greater splanchnic nerve, while the lower part, which is more or less detached and is named the *aorticorenal* ganglion, receives the lesser splanchnic nerve and gives off the greater part of the renal plexus.

The secondary plexuses springing from or connected with the cœliac plexus are the following :

Phrenic.	Splenic.	Suprarenal.	Testicular (or ovarian).
Hepatic.	Left gastric.	Renal.	Superior mesenteric,
	Abdominal aortic.	Inferior mesenteric.	

The **phrenic plexus** accompanies the corresponding phrenic artery to the diaphragm, some filaments passing to the suprarenal gland. It arises from the upper part of the celiac ganglion, and is larger on the right than on the left side. It receives one or two branches from the phrenic nerve. At the point of junction of the right phrenic plexus with the phrenic nerve there is a small ganglion (*phrenic ganglion*). This plexus distributes some branches to the inferior vena cava, and to the suprarenal and hepatic plexuses.

The **hepatic plexus** is the largest offset from the celiac plexus; it also receives filaments from the left and right vagus and right phrenic nerves. It accompanies the hepatic artery and portal vein and their branches into the liver, and in the liver the nerves are confined to the vicinity of the blood vessels. Branches from the plexus accompany all the branches of the hepatic artery. Those passing to the gall bladder form a scanty cystic plexus; branches also pass to the bile ducts. The branches accompanying the right gastric artery supply the pylorus. A considerable plexus accompanies the gastroduodenal artery and its branches. From this plexus branches pass to the pylorus and first part of the duodenum. Many of the nerves pass with the right gastro-epiploic artery to supply the right part of the stomach and the greater curvature. Others pass with the superior pancreaticoduodenal artery and supply the second part of the duodenum, head of the pancreas and the lower part of the bile duct. The hepatic plexus contains both afferent and efferent sympathetic and parasympathetic fibres, and it is believed that the vagal constituents are motor to the musculature of the gall bladder and bile ducts and inhibitory to the sphincter of the bile duct.

The **left gastric plexus** accompanies the left gastric artery along the lesser curvature of the stomach, and joins with the gastric branches of the vagus nerves. The gastric sympathetic nerves are motor to the pyloric sphincter but inhibitory to the muscular coats of the stomach.

The **splenic plexus** is formed by branches from the celiac plexus, left celiac ganglion and right vagus nerve. It accompanies the splenic artery to the spleen, giving off, in its course, subsidiary plexuses along the various branches of the artery. The terminal branches supply the unstriped muscle of the splenic capsule and trabeculae.

The **suprarenal plexus** is formed by branches from the celiac ganglion, celiac plexus and the greater splanchnic nerve. Relative to its size, the suprarenal gland has a more profuse nerve supply than any other organ. The nerves are mainly medullated, and are *preganglionic** in nature, being distributed to the medulla of the gland and ending about the chromaffin cells (phaeochromocytes), which are homologous with postganglionic sympathetic neurons (see Embryology Section, p. 145). A few nerves are unmedullated, postganglionic fibres and are distributed to the cortical branches of the suprarenal artery.

The **renal plexus** is a rich plexus formed by filaments from the celiac ganglion, celiac plexus, aorticorenal ganglion, lowest thoracic splanchnic nerve, first lumbar splanchnic nerve and the aortic plexus. Small collections of nerve cells are found in the plexus, the largest usually lying behind the commencement of the renal artery. The plexus is continued into the kidney around the branches of the renal artery to supply the vessels and the renal glomeruli and tubules, particularly the tubules in the cortex of the kidney. For the main part the renal nerves are vasomotor in function. From the renal plexus branches are given to the ureteric and the testicular (or ovarian) plexuses. The upper part of the ureter receives its nerve supply by branches from the renal and aortic plexuses, the middle part by branches from the superior hypogastric plexus and the hypogastric nerve, and the lower part by branches from the hypogastric nerve and the inferior hypogastric plexus.

The **testicular plexus** accompanies the testicular artery to the testis. Its upper part is formed by branches from the renal and aortic plexuses. Lower down the plexus is reinforced by branches from the superior and inferior hypogastric plexuses. Branches from the plexus pass to the epididymis and the ductus deferens.

The **ovarian plexus** accompanies the ovarian artery and is distributed to the ovary and uterine tube. The upper part of the plexus is formed by branches from the renal and aortic plexuses; lower down it is reinforced by branches from the superior and inferior hypogastric plexuses.

The nerves in the testicular, or ovarian, plexuses contain efferent and afferent

* T. R. Elliott, *J. Physiol.*, 46, 1913; J. Z. Young, *J. Anat.*, 73, 1939.

sympathetic fibres; the efferent fibres are vasomotor in nature and are derived from the tenth and eleventh thoracic segments of the spinal cord; the afferent (pain) fibres have their cells of origin in the ganglia on the posterior roots of the tenth and eleventh thoracic spinal nerves. The parasympathetic fibres derived from the inferior hypogastric plexuses are probably vasodilator in nature.

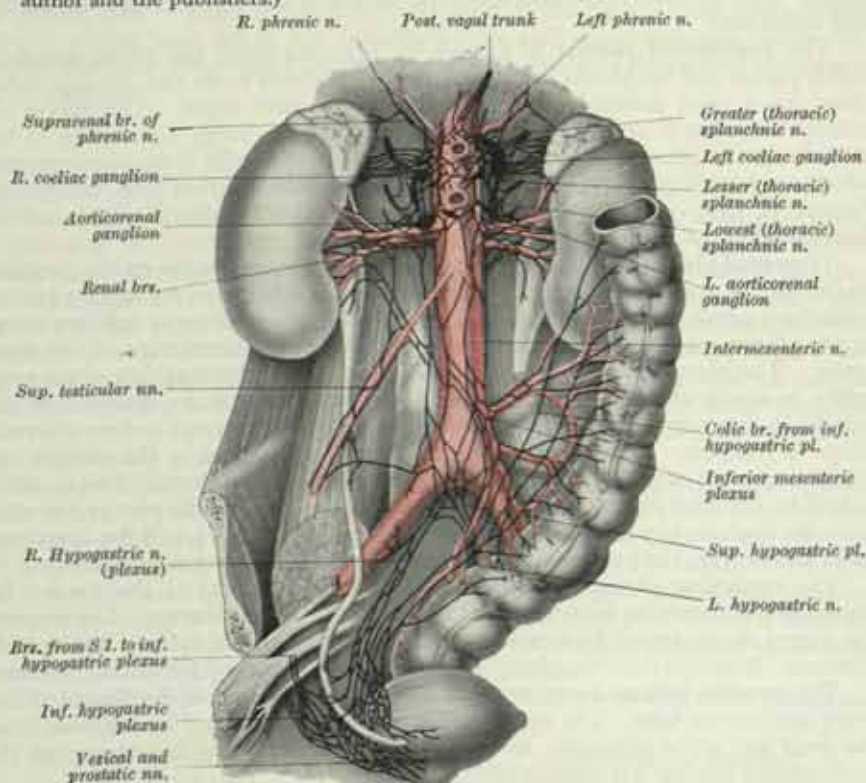
The **superior mesenteric plexus** is a continuation of the lower part of the celiac plexus, and receives a branch from the junction of the right vagus nerve with the latter plexus. It surrounds the superior mesenteric artery, accompanies it into the mesentery, and divides into a number of secondary plexuses which are distributed to the parts supplied by the artery, viz. pancreatic branches to the pancreas; jejunal and ileal branches to the small intestine; ileocolic, right colic, and middle colic branches, which supply the corresponding parts of the large intestine. The **superior mesenteric ganglion** is situated in the upper part of the plexus, usually close above the origin of the superior mesenteric artery.

The sympathetic nerves to the intestine are motor to the ileocaecal sphincter but inhibitory to the muscular coats of the gut. In addition, they convey vasoconstrictor fibres.

The **abdominal aortic plexus** (intermesenteric plexus) is formed by branches from the celiac plexus and ganglia, and receives filaments from the first and second lumbar splanchnic nerves. It is situated upon the sides and front of the aorta, between the origins of the superior and inferior mesenteric arteries. It is not a dense plexus but consists of four to twelve nerves (intermesenteric nerves) connected by obliquely arranged branches. It is continuous above with the celiac plexus and the celiac and aorticorenal ganglia, and below with the superior hypogastric plexus. From this plexus parts of the testicular, the inferior mesenteric, the iliac and the superior hypogastric plexuses arise; it also distributes filaments to the inferior vena cava.

The **inferior mesenteric plexus** is derived chiefly from the aortic plexus, but

FIG. 999.—Autonomic nerves and plexuses in the abdomen and pelvis. (After G. A. G. Mitchell, *Anatomy of the Autonomic Nervous System*, by the courtesy of the author and the publishers.)



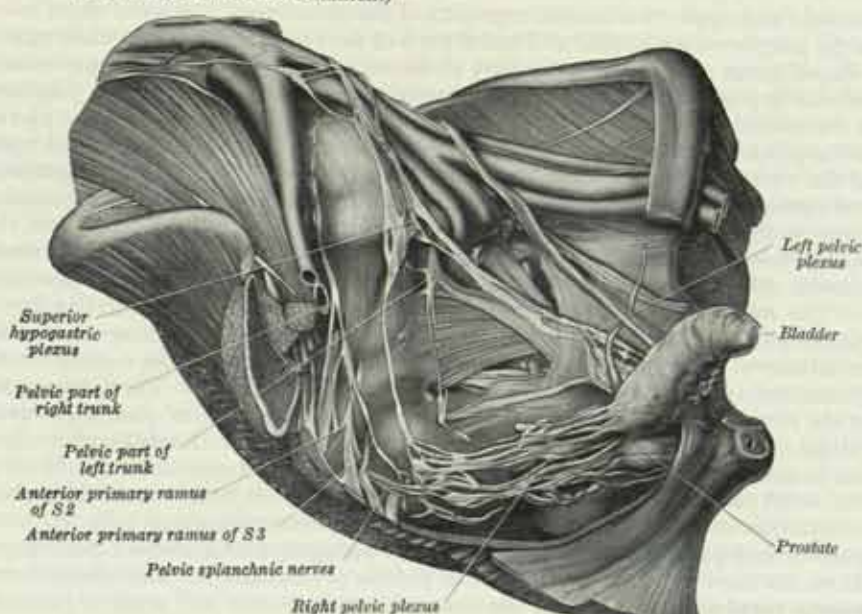
Note the ascending branches of the inferior hypogastric plexus passing up to supply the descending colon. The sympathetic trunks are not shown on the right side; note the upper, middle and lower ureteric nerves.

also receives branches from the second and third lumbar splanchnic nerves. It surrounds the inferior mesenteric artery and is distributed along its branches; thus the left colic plexus supplies the left part of the transverse colon, the descending colon and sigmoid colon, and the superior rectal plexus supplies the rectum. Just above, or below, the origin of the inferior mesenteric artery, a ganglion (the *inferior mesenteric ganglion*) may sometimes be found, but more often small discrete ganglia are scattered about the commencement of the artery in the proximal part of the plexus. The colic sympathetic nerves are inhibitory to the muscular coats of the colon and rectum. Branches from the parasympathetic pelvic splanchnic nerves run up through or near the superior hypogastric and the inferior mesenteric plexuses to supply the large intestine from the left part of the transverse colon down as far as the rectum (see pp. 1200, 1448); impulses along these nerves cause contraction of the musculature of the gut.

THE SUPERIOR HYPOGASTRIC PLEXUS (figs. 998, 999, 1000)

The **superior hypogastric plexus** is situated in front of the bifurcation of the abdominal aorta, the left common iliac vein, the median sacral vessels, the body of the last lumbar vertebra and the promontory of the sacrum, and between the two common iliac arteries. It is often referred to as 'the presacral nerve', but the plexus is seldom sufficiently condensed so as to resemble a single nerve and moreover the plexus is prelumbar rather than presacral in position. It lies in the extra-peritoneal connective tissue, and the parietal peritoneum can easily be stripped off its anterior surface. The plexus varies in breadth and in the degree of condensation of its constituent nerves, and it often lies a little to one side of the median plane (more often to the left side); the root of the sigmoid mesocolon, containing the superior rectal vessels, lies to the left side of the lower part of the plexus. Scattered nerve cells are found in the plexus.

FIG. 1000.—The pelvic portion of the sympathetic system, viewed from in front and from the right side, a large portion of the right hip-bone having been removed. The superior hypogastric plexus is seen to divide below into the right and left hypogastric nerves (which are not labelled), which run down to the pelvic plexuses (inferior hypogastric plexuses). (Drawn from a dissection by the late Dr. G. D. Channell.)



Above, the plexus is formed by the union of branches from the aortic plexus with the third and fourth lumbar splanchnic nerves. Below, the plexus divides

into the right and left hypogastric nerves which descend to the inferior hypogastric plexus. The superior hypogastric plexus gives off branches to the ureteric and testicular (or ovarian) plexuses and to the plexus on the common iliac arteries. In addition to the sympathetic fibres which descend to form the superior hypogastric plexus, the plexus may contain parasympathetic fibres (from the pelvic splanchnic nerves) which ascend from the inferior hypogastric plexus, though usually these parasympathetic fibres run up to the left of the superior hypogastric plexus and across the sigmoid vessels and the branches of the left colic vessels. These parasympathetic fibres are distributed partly along the branches of the inferior mesenteric artery, but also as independent retroperitoneal nerves, to supply the left part of the transverse colon, the left colic flexure, the descending colon and the sigmoid colon (see pp. 1200, 1448 and fig. 999).

THE INFERIOR HYPOGASTRIC (OR PELVIC) PLEXUSES (fig. 1000)

The superior hypogastric plexus divides below into the right and left *hypogastric nerves*, which run down in the extraperitoneal connective tissue into the pelvis, medial to the internal iliac artery and its branches, to join the inferior hypogastric plexus. Each nerve may be single or may form an elongated narrow plexus consisting of two or three longitudinal nerves connected by anastomosing filaments. From each hypogastric nerve branches may pass to the testicular (or ovarian) plexus, the ureteric plexus, the plexus on the internal iliac artery and to the sigmoid colon, and each nerve may be joined near its commencement by the lowest lumbar splanchnic nerve.

Each **inferior hypogastric (or pelvic) plexus** in the male is situated on the side of the rectum, seminal vesicle, prostate and the posterior part of the urinary bladder; in the female, each plexus is placed on the side of the rectum, uterine cervix, vaginal fornix and posterior part of the urinary bladder, and extends into the base of the broad ligament of the uterus. The plexuses lie in the extraperitoneal connective tissue and contain numerous small ganglia. Each plexus is formed by the hypogastric nerve, which conveys most of the sympathetic fibres to the plexus, and by branches from the ganglia on the sacral part of the sympathetic trunk (usually the second and third ganglia), which convey only a few fibres to the plexus; the parasympathetic fibres in the plexus are derived from the pelvic splanchnic nerves. The preganglionic efferent sympathetic fibres originate in the lower three thoracic and upper two lumbar segments of the spinal cord; some of these relay in the ganglia on the lumbar and sacral parts of the sympathetic trunk, while others synapse about cells in the lower part of the aortic plexus and in the superior and inferior hypogastric plexuses. The preganglionic parasympathetic fibres originate in the second, third, and fourth sacral segments of the spinal cord, reach the plexus in the pelvic splanchnic nerves and synapse about cells in the plexus or in the walls of the viscera supplied by the branches of the plexus. The afferent sympathetic and parasympathetic fibres have their cells of origin in the ganglia on the posterior roots of the lower thoracic, upper lumbar and upper sacral nerves. From the plexus numerous branches are distributed to the pelvic (and some abdominal) viscera, either directly or by accompanying the branches of the internal iliac artery.

The **middle rectal plexus** arises from the upper part of the inferior hypogastric plexus; the fibres pass to the rectum either directly or along the middle rectal artery. The plexus communicates above with branches of the superior rectal plexus and extends inferiorly as far as the internal anal sphincter. The nerve supply of the rectum and anal canal is derived from (a) the superior rectal plexus (p. 1219), (b) the middle rectal plexus and (c) the inferior rectal (haemorrhoidal) nerves which are branches of the pudendal nerve (p. 1190). The efferent sympathetic fibres in the rectal plexuses are concerned with inhibition of the expulsive musculature and contraction of the sphincter. Afferent pain impulses pass along both the sympathetic and parasympathetic nerves, but the parasympathetic afferent and efferent fibres are more important in the normal process of defaecation. The inferior rectal nerves supply motor fibres to the external anal sphincter and sensory (somatic) fibres to the lower (ectodermal) part of the anal canal (p. 1445).

The **vesical plexus** arises from the anterior part of the inferior hypogastric plexus. It is composed of numerous nerves which accompany the vesical arteries to the bladder. Branches from the plexus pass to the seminal vesicles and deferent

ducts. Many small collections of nerve cells are present among the nerve fibres in the muscular wall of the bladder. The sympathetic preganglionic efferent fibres in the plexus arise from the lower two thoracic and upper two lumbar segments of the spinal cord; the cells about which they synapse are probably scattered in the superior and inferior hypogastric plexuses and in the wall of the bladder. The parasympathetic preganglionic efferent fibres arise from the second, third and fourth sacral segments of the spinal cord and synapse about cells near to or in the wall of the bladder. Sensory fibres pass from the bladder in both parasympathetic and sympathetic nerves. Pain fibres pass in the pelvic splanchnic nerves to their cells of origin in the ganglia on the posterior roots of the upper sacral nerves, and also in the hypogastric nerves, superior hypogastric plexus and lumbar splanchnic nerves to reach their cells of origin in the ganglia on the posterior roots of the lower thoracic and upper lumbar nerves. Sensations aroused by distention are mediated by the afferent sympathetic nerves. The efferent parasympathetic nerves convey motor fibres to the muscular coats of the bladder and inhibitory fibres to the sphincter. The efferent sympathetic nerves convey motor fibres to the sphincter and inhibitory fibres to the muscular coats, though some observers maintain that the sympathetic fibres are mainly vasomotor in function and that filling and emptying of the bladder are normally controlled exclusively by the parasympathetic nerves.

The **prostatic plexus** arises from the lower part of the inferior hypogastric plexus and is composed of relatively large nerves which enter the base and sides of the prostate and contain collections of nerve cells. The nerves are distributed to the prostate, seminal vesicles, prostatic urethra, ejaculatory ducts, corpora cavernosa, corpus spongiosum, membranous and penile parts of the urethra and the bulbo-urethral glands. The nerves supplying the corpora cavernosa form two sets of nerves, the lesser and the greater cavernous nerves of the penis; these arise from the front part of the prostatic plexus, join with branches from the pudendal nerve and then pass forwards below the pubic arch. The filaments of the *lesser cavernous nerves* pierce the fibrous covering of the penis near its root and supply the erectile tissue of the corpus spongiosum and the penile urethra. The *greater cavernous nerves* run forwards on the dorsum of the penis, communicate with the dorsal nerve of the penis and are distributed to the erectile tissue; some of the filaments pass to the erectile tissue of the corpus spongiosum. The sympathetic nerves supplying the male genital organs produce vasoconstriction while the parasympathetic produce vasodilatation.

The seminal vesicles are supplied by nerves derived from the vesical plexus, the prostatic plexus and the lower part of the inferior hypogastric nerves. From these nerves, filaments pass to the ejaculatory ducts and to the ductus deferens. It is generally believed that constriction of the seminal vesicles and seminal ejaculation are brought about by the sympathetic system, which also produces inhibition of the bladder musculature and contraction of its sphincter during ejaculation thus preventing reflex of the seminal fluid into the bladder. Mitchell,* however, suggests that contraction of the seminal vesicles is due to parasympathetic impulses.

The uterine nerves arise from the inferior hypogastric plexus, predominantly from the part of the plexus lying in the base of the broad ligament and known as the **utero-vaginal plexus**. From the plexuses some nerves pass down with the vaginal arteries (*see below*), while others pass directly to the cervix uteri, or upwards with or near the uterine arteries in the broad ligament. The nerves passing to the cervix form a plexus in which small paracervical ganglia are found, one ganglion sometimes being large and called the *uterine cervical ganglion*. The uterine nerves passing upwards with the uterine arteries supply branches to the body of the uterus and, in the upper part of the broad ligament they supply branches to the uterine tube and communicate with the tubal nerves from the inferior hypogastric plexus and with the nerves of the ovarian plexus. The branches of the uterine nerves ramify in the myometrium and endometrium; most of these nerves accompany the vessels. The efferent preganglionic sympathetic fibres supplying the uterus are derived from the last thoracic and first lumbar segments of the spinal cord; the sites of the cells about which they synapse are not known. The preganglionic parasympathetic fibres arise in the second, third and fourth sacral segments of the cord and relay in the paracervical ganglia. While activity of the sympathetic nerves

* G. A. G. Mitchell, *Anatomy of the Autonomic Nervous System*, 1953. E. and S. Livingstone, Edinburgh and London, p. 307.

may produce uterine contraction and vasoconstriction, and that of the parasympathetic nerves produce uterine inhibition and vasodilatation, the results of the activities of these two systems are complicated by the pronounced hormonal control of uterine functions. Afferent pain fibres from the cervix uteri pass by the parasympathetic pelvic splanchnic nerves to their cells of origin on the posterior roots of the upper sacral nerves. Pain fibres from the body of the uterus pass in the sympathetic nerves through the superior hypogastric plexus and the lumbar splanchnic nerves to the cells on the posterior roots of the lowest thoracic and upper lumbar nerves. Thus surgical section of the superior hypogastric plexus is employed for the relief of painful menstruation (dysmenorrhœa).

The *vaginal nerves* arise from the lower parts of the inferior hypogastric and utero-vaginal plexuses, and follow the vaginal arteries and their branches to be distributed to the walls of the vagina, the erectile tissue of the vestibular bulbs and the clitoris (cavernous nerves of the clitoris), the urethra and the greater vestibular glands. The nerves contain numerous parasympathetic fibres which have a vasodilator effect on the erectile tissue.

Applied Anatomy.—Various parts of the sympathetic nervous system are removed surgically in the treatment of a number of clinical conditions. In operations on the efferent side of the sympathetic, ganglia on the sympathetic trunk are removed, or preganglionic fibres cut, rather than postganglionic fibres severed, since the latter procedure may be followed by regeneration of the nerves. For example, the arteries of the limbs may be denervated in conditions of vascular spasm (Raynaud's disease) or in organic arterial disease where spasm is also present; the parts of the system removed are described above (pp. 1210, 1211). In the treatment of essential hypertension, much more extensive sympathectomy is performed, involving bilateral removal of the sympathetic trunks (from the eighth thoracic to the first lumbar ganglia) and the greater and lesser thoracic splanchnic nerves.

Sympathectomy is also performed for the relief of pain, for example in cases of severe angina pectoris (see p. 1215). Division of the superior hypogastric plexus (presacral neurectomy) does not completely relieve pain associated with disease of the pelvic organs, since, as noted above, many of the pain fibres pass in the pelvic splanchnic nerves. The pain fibres from the body of the uterus, however, pass in the sympathetic nerves via the superior hypogastric plexus, so that this operation is successful in cases of intractable painful menstruation (dysmenorrhœa).

In the male, resection of the superior hypogastric plexus is followed by loss of the power of ejaculation and consequent sterility, owing to the interruption of the sympathetic pathway to the seminal vesicles, deferent ducts and prostate. Knowledge of the pathways pursued by these nerves between the ganglia on the sympathetic trunk and the superior hypogastric plexus is less exact and the pathways may vary in different cases, but in certain individuals the outflow from the first lumbar, and possibly the twelfth thoracic, ganglion is of major importance while in others the fibres from the third lumbar ganglion are of equal importance.*

* J. C. White, R. H. Smithwick and F. A. Simeone, *The autonomic nervous system*, Third edition, 1952, H. Kimpton, London, p. 399.

THE ORGANS OF THE SENSES AND THE SKIN

THE organs of the senses may be divided into (a) those of the special senses of taste, smell, sight, and hearing, and (b) those associated with the general sensations of touch, pressure, pain, heat, cold and proprioception. The latter have been described already (p. 922).

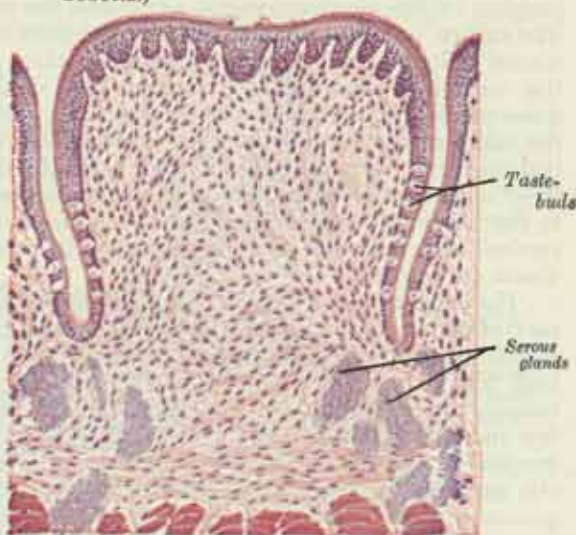
THE PERIPHERAL ORGANS OF THE SPECIAL SENSES

THE ORGAN OF TASTE

The peripheral gustatory organs, or organs of taste, comprise the *taste-buds* (*gustatory calyculi*), which are composed of modified epithelial cells arranged in flask-shaped groups (fig. 1002) in the epithelium covering the tongue, the inferior surface of the soft palate, the palato-glossal arches, the posterior surface of the epiglottis and the posterior wall of the oral part of the pharynx. They are most numerous on the sides of the vallate papillæ of the tongue (fig. 1001), less so on the walls surrounding these papillæ; they are plentiful over the *folia linguæ* and the posterior third of the tongue but are distributed sparingly on the fungiform papillæ of the tongue, the soft palate, epiglottis and pharynx. They are more numerous in the infant than the adult and their atrophy increases with age; those on the extreme posterior part of the tongue and on the epiglottis disappear early in life. There are no taste-buds in the mid-dorsal region of the oral part of the tongue.

Structure.—Each taste-bud is flask-shaped (fig. 1002), its broad base resting on the corium, and its neck opening between the cells of the epithelium by an orifice termed the *gustatory pore*. The bud consists of supporting cells and gustatory cells. The *supporting cells* are mostly arranged like the staves of a cask, and form a complete envelope for the bud. Some, however, are found in the interior of the bud between the gustatory cells. The *gustatory cells* occupy the central portion of the bud; they are spindle-shaped, and each possesses a large spherical nucleus near its centre. The peripheral process of the cell ends at the gustatory pore in a fine hair-like filament, named the *gustatory hair*. The central process passes towards the deep part of the bud, and there ends in a single or branched extremity. Transitional cells, intermediate in type between the gustatory and supporting cells are present, and may be concerned with replacing degenerating gustatory cells. Nerve-fibres from one of the gustatory nerves, after losing their medullary sheaths, enter the taste-bud, and end in fine fibrils between the gustatory cells; their

FIG. 1001.—Section through a vallate papilla. Stained with hæmatoxylin and eosin. $\times \text{ } \bar{c} \text{ } 25$. (After Sobotta.)



presence is a constant and characteristic feature. Other nerve-fibrils end between the epithelial cells which surround the taste-bud, but these are believed to be nerves of ordinary sensation and not gustatory. All taste-buds are similar morphologically, yet there are four distinct taste qualities, namely, bitter, sour (acid), sweet and salt. The tip of the tongue

FIG. 1002.—Section through a taste-bud.
Semi-diagrammatic. $\times 8450$.



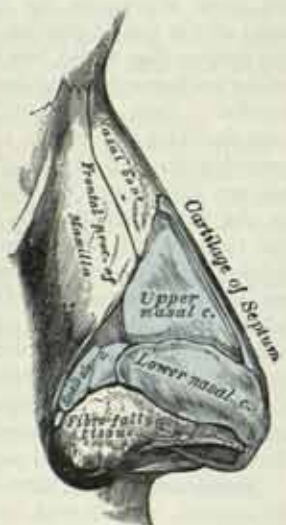
is most sensitive to sweet and salt stimuli; the lateral margins to sour stimuli and the pharyngeal part of the tongue to bitter stimuli; the mid-dorsal region is relatively insensitive. Flavours result from the integration of gustatory and olfactory stimuli. Baradi and Bourne* studied the distribution of enzymes (e.g. phosphatases, esterase) in the regions of the taste-buds and conclude that the gustatory cells function as a focusing point of a taste unit which includes the neighbouring epithelium. They consider taste to be a series of patterns of nerve impulses evoked by the differential inhibition

or stimulation of enzymes or enzyme systems in and around the taste-buds, each type of taste being represented by a specific pattern.

Nerves of taste.—The taste nerve-fibres are the peripheral processes (dendrites) of pseudo-unipolar nerve cells in the ganglion of the facial nerve, the inferior ganglion of the glossopharyngeal nerve and the inferior ganglion of the vagus. The central processes of these cells (axons) form the tractus solitarius (p. 954), and from the nucleus of that tract fibres ascend through the brain stem in the dorso-medial part of the medial lemniscus to reach the infero-medial part of the lateral nucleus of the thalamus (the arcuate nucleus) and probably the hypothalamus. From the thalamus they are relayed to the lowermost part of the postcentral gyrus of the cerebral cortex, as well as to the region of the limen insulae (p. 1027).

The nerve of taste for the anterior two-thirds (oral part) of the tongue, excluding the vallate papillae, is the chorda tympani (through the lingual nerve); these taste fibres in most individuals pass in the chorda tympani to the ganglion of the facial nerve. In a few individuals, these taste fibres leave the chorda tympani by anastomotic branches connecting it to the otic ganglion (p. 1119) and proceed thence in the greater petrosal nerve to the ganglion of the facial nerve.† The taste-buds on the under surface of the soft palate are also supplied mainly by the facial nerve, through the greater petrosal nerve, the nerve of the pterygoid canal and the palatine nerves (p. 1106); the glossopharyngeal also contributes to their supply. The taste-buds on the vallate papillae and the pharyngeal part of the tongue, and on the palatoglossal arches and the oral part of the pharynx are innervated by the glossopharyngeal, while those on the extreme back part of the tongue and on the epiglottis are supplied by the internal laryngeal part of the superior laryngeal branch of the vagus.

FIG. 1003.—The cartilages of the right side of the nose. Lateral aspect.



THE ORGAN OF SMELL

The peripheral olfactory organ consists of the *external nose*, and the *nasal cavity*, which is divided by a septum into right and left parts.

* A. F. Baradi and G. H. Bourne, *Nature*, *London*, 1951, **168**, 977.

† H. Schwartz and G. Weddell, *Brain*, **61**, 99, 1938.

The **external nose** is pyramidal in form, and its upper angle, or *root*, is connected directly with the forehead; its free angle is termed the *apex*. Its inferior aspect is perforated by two elliptical apertures, termed the *nares* or *nostrils*, which are separated from each other by the septum. The lateral surfaces of the nose form, by their union in the median plane, the *dorsum nasi*, the shape and direction of which vary considerably in different individuals; the upper part of the external nose is supported by the nasal bones and the frontal processes of the maxillæ. The lateral surfaces end below in the rounded *alæ nasi*.

The framework of the external nose (fig. 1003) is composed of bones and hyaline cartilages. The *bony framework*, which supports its upper part, consists of the nasal bones, the frontal processes of the maxillæ, and the nasal part of the frontal bone. The *cartilaginous framework* consists of the septal cartilage, the upper and lower nasal cartilages, and the small cartilages of the ala (figs. 1003-1005). These are connected with one another and with the bones by the continuity of the perichondrium and the periosteum.

The *septal cartilage* (figs. 1004, 1005), somewhat quadrilateral in form, and

FIG. 1004.—The cartilages of the nose, inferior aspect.

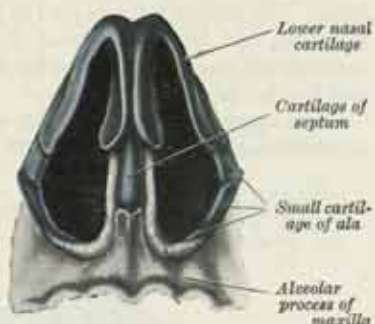
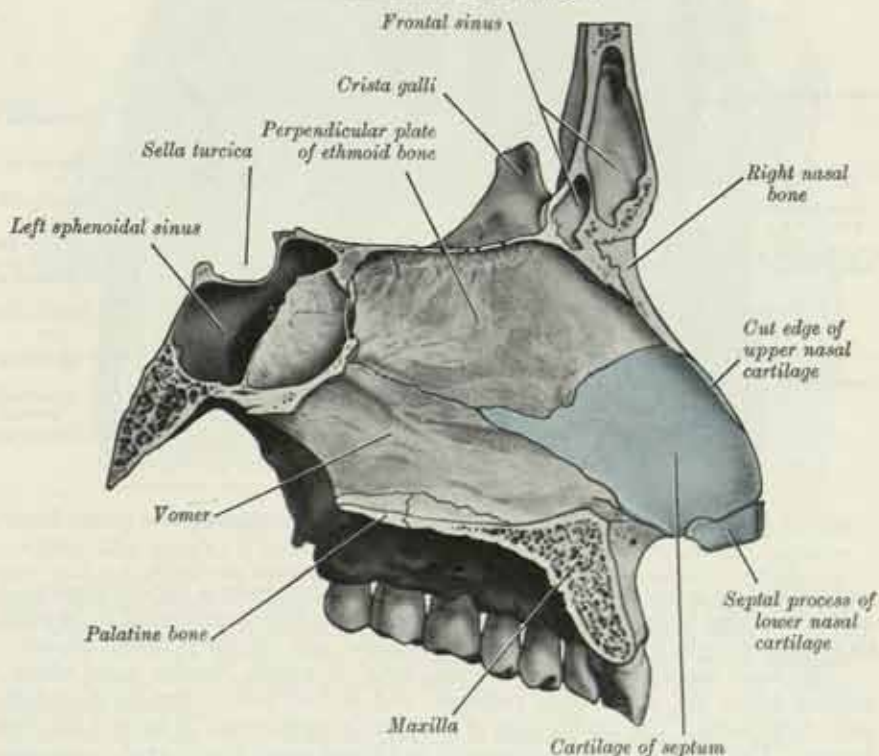


FIG. 1005.—The right side of the septum of the nose, showing its constituent bones and cartilages.

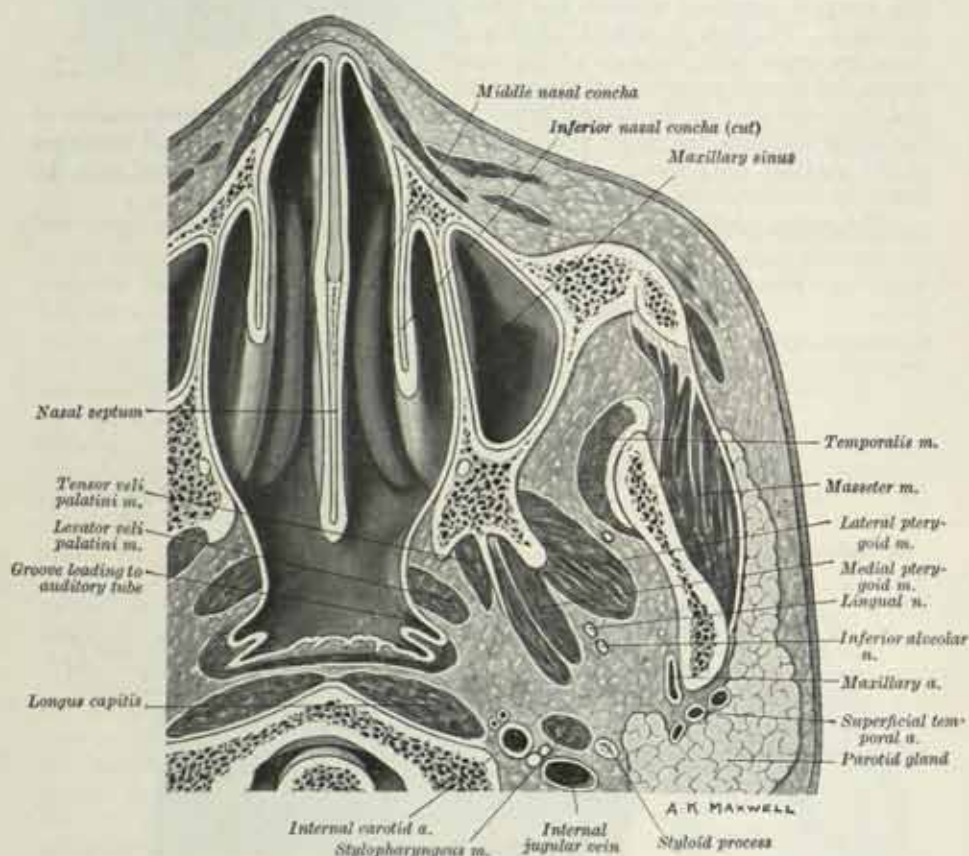


thicker at its margins than at its centre, forms almost the whole of the septum between the anterior parts of the nasal cavity. The upper part of its antero-superior margin is connected to the posterior border of the internasal suture; the middle part is continuous with the upper nasal cartilages; the lower part is attached to these cartilages by the perichondrium. Its antero-inferior border is connected on each side to the septal process of the lower nasal cartilage. Its posterosuperior

border is joined to the perpendicular plate of the ethmoid bone, and its postero-inferior border is attached to the vomer and to the nasal crest of the maxillæ and the anterior nasal spine. The cartilage of the septum may extend backwards (especially in children) as a narrow process, termed the *sphenoidal process*, for some distance between the vomer and the perpendicular plate of the ethmoid bone. The antero-inferior part of the nasal septum between the two nostrils is freely movable, and hence is named the *septum mobile nasi*; it is not formed by the cartilage of the septum, but by the septal processes of the lower nasal cartilages and by the skin.

The *upper nasal cartilage* (fig. 1003) is triangular in shape. Its anterior margin is thicker than the posterior, and its upper part is continuous with the cartilage of the

FIG. 1006.—A transverse section through the anterior part of the head at a level just below the apex of the odontoid process. Viewed from below.



septum, but its lower part is separated from this cartilage by a narrow fissure; its superior margin is attached to the nasal bone and the frontal process of the maxilla; its inferior margin is connected by fibrous tissue with the lower nasal cartilage.

The *lower nasal cartilage* (figs. 1003, 1004) is a thin, flexible plate which is situated below the upper nasal cartilage, and is bent acutely around the anterior part of the naris. The medial part of the plate is narrow, and is termed the *septal process*. The latter is loosely connected by fibrous tissue with that of the opposite cartilage, and to the antero-inferior part of the septal cartilage, thus helping to form the *septum mobile nasi*. The upper border of the lateral part of the lower nasal cartilage is attached by fibrous tissue to the lower border of the upper nasal cartilage. Its posterior, narrow end is connected with the frontal process of the maxilla by a tough fibrous membrane, in which three or four small cartilaginous plates, termed the *small cartilages of the ala* (fig. 1003), are found. Its lower, free edge falls short of the lateral margin of the naris, the lower part of the ala nasi being

formed by fatty and fibrous tissue covered with skin. In front, the lower nasal cartilages are separated by a notch which can be felt at the apex of the nose.

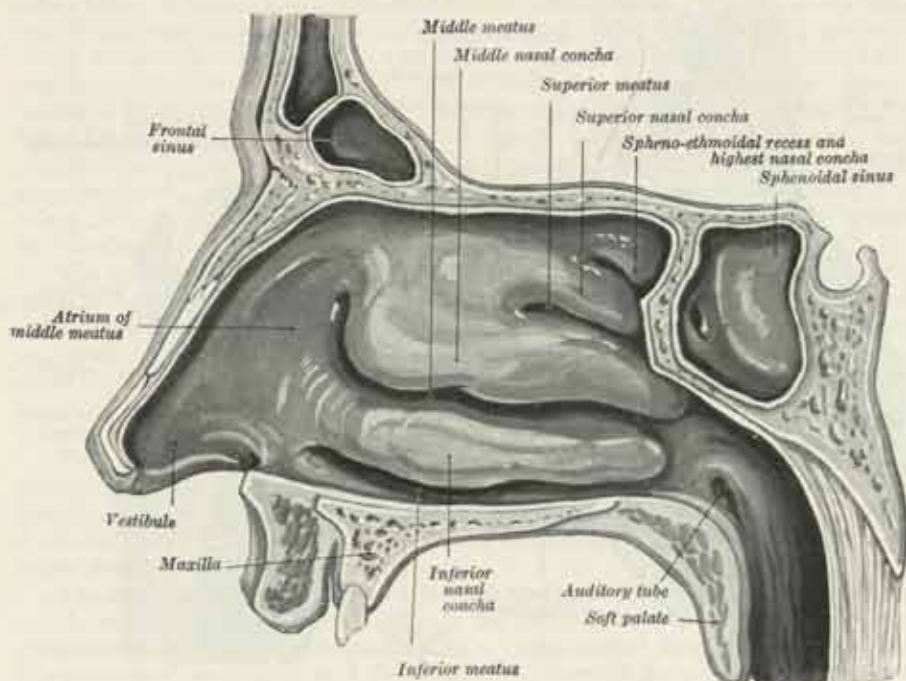
The *muscles* acting on the external nose have been described on p. 556.

The *skin* of the dorsum and sides of the nose is thin, and loosely connected with the subjacent parts; but over the tip and alæ it is thicker and more firmly adherent, and is furnished with a large number of sebaceous follicles, the orifices of which are usually very distinct.

The *arteries* of the external nose are the alar and septal branches of the facial artery, which supply the ala and lower part of the septum; and the dorsal nasal branch of the ophthalmic artery and the infra-orbital branch of the maxillary artery, which supply the lateral aspects and the dorsum. The *veins* end in the facial and ophthalmic veins.

The *nerves* for the muscles of the nose are derived from the facial nerve, while the skin receives branches from the ophthalmic nerve, through its infratrochlear branch and the external nasal nerve (p. 1103), and from the infra-orbital branch of the maxillary nerve (p. 1106).

FIG. 1007.—The lateral wall of the right half of the nasal cavity.



Nasal cavity.—The nasal cavity is subdivided into right and left halves by the nasal septum (fig. 1006). These two halves open on the face through the nares or nostrils, and communicate behind with the nasal part of the pharynx through the posterior nasal apertures. The *nares* are somewhat pear-shaped apertures, narrower in front than behind. Each measures from 1.5 cm. to 2 cm. anteroposteriorly, and from 0.5 cm. to 1 cm. transversely. The *posterior nasal apertures* or *choanae* are two oval openings, each measuring about 2.5 cm. in the vertical and 1.25 cm. in the transverse direction.

For the description of the bony boundaries of the nasal cavity, see p. 299.

Each half of the nasal cavity has a floor, a roof, a lateral wall and a medial wall which is formed by the septum. It can be subdivided into three parts, viz.: the vestibule, the olfactory region and the respiratory region.

The *vestibule* is a slight dilatation just inside the aperture of the nostril (fig. 1007), bounded laterally by the ala and the lateral part of the lower nasal cartilage, and medially by the septal process of the same cartilage; it extends as a small recess towards the apex of the nose. The vestibule is lined with skin, and coarse hairs and sebaceous and sweat glands are found in its lower part; the hairs (*vibrissæ*) curve

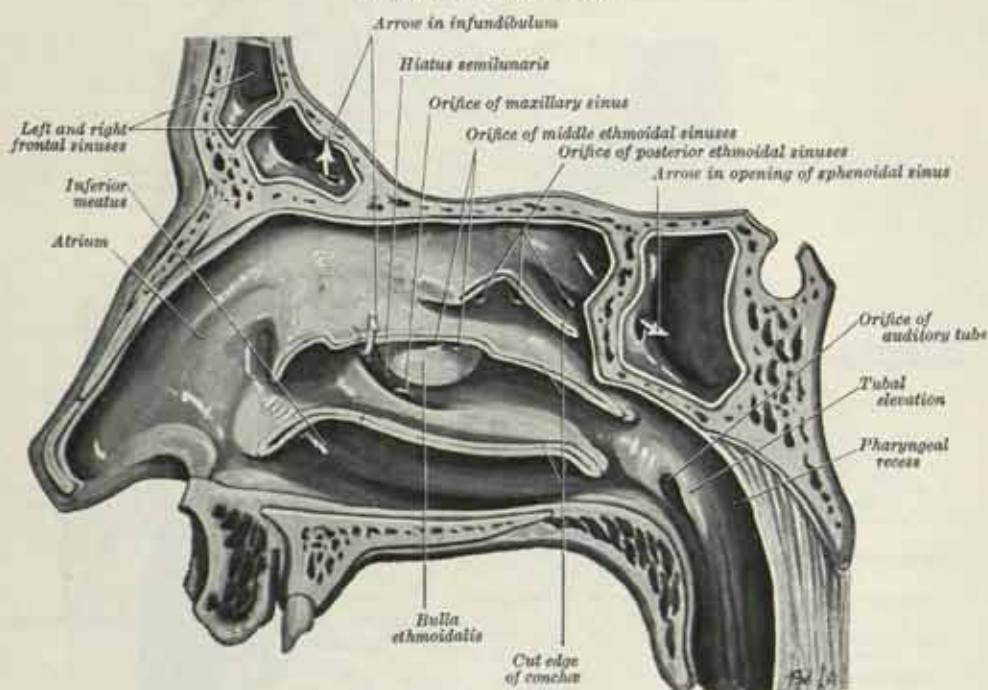
downwards and forwards to the naris, and tend to arrest the passage of foreign substances carried with the current of inspired air. The vestibule is limited above and behind by a curved elevation, named the *limen nasi*, which corresponds to the upper margin of the lower nasal cartilage, and along which the skin of the vestibule is continuous with the mucous membrane of the nasal cavity.

The **olfactory region** is limited to the superior nasal concha and the opposed part of the septum.

The **respiratory region** comprises the rest of the cavity.

Walls of the nasal cavity.—The **lateral wall** (figs. 1007, 1008) is marked by three elevations, formed by the superior, middle and inferior nasal conchæ, and below and lateral to each concha by the corresponding nasal passage or meatus. Above the superior concha a triangular fossa, named the *spheno-ethmoidal recess*, receives the opening of the sphenoidal sinus. Sometimes a fourth elevation, termed the highest nasal concha, is present on the lateral wall of the spheno-ethmoidal

FIG. 1008.—The lateral wall of the right half of the nasal cavity; the three nasal conchæ have been removed.



recess (fig. 1007); the highest or supreme nasal meatus related to it may present the opening of a posterior ethmoidal sinus. The *superior meatus* is a short oblique passage extending about half-way along the upper border of the middle concha; the posterior ethmoidal sinuses open, usually by one or two apertures, into the front part of this meatus. The *middle meatus*, deeper in front than behind, is below and lateral to the middle concha, and is continued anteriorly into a shallow depression situated above the vestibule and named the *atrium* of the middle meatus. Above the atrium an ill-defined curved ridge, termed the *aggr nasi* (p. 345), runs forwards and downwards from the upper end of the anterior free border of the middle concha; it is better developed in the new-born child than in the adult. When the middle concha is raised or removed the lateral wall of this meatus is displayed fully. A rounded elevation, termed the *bulla ethmoidalis*, and, below and extending upwards in front of it, a curved cleft, termed the *hiatus semilunaris*, form the principal features of this wall. The *bulla ethmoidalis* is caused by the bulging of the middle ethmoidal sinuses, which open on or immediately above it, and the size of the bulla varies with that of its contained sinuses. The *hiatus semilunaris*, which is bounded inferiorly by a sharp concave ridge produced by the uncinat process of the ethmoid bone, leads forwards and upwards into a curved channel, which is

named the *ethmoidal infundibulum*. The anterior ethmoidal sinuses open into the infundibulum, which in rather more than 50 per cent. of subjects is continuous with the frontonasal duct or passage leading from the frontal sinus. In other cases the ethmoidal infundibulum ends blindly in front by forming one or more of the anterior ethmoidal sinuses (infundibular sinuses), and the frontonasal duct open directly into the anterior end of the middle meatus. The opening of the maxillary sinus is situated below the bulla ethmoidalis, and is usually hidden by the flange-like lower (or medial) edge of the hiatus semilunaris; in a coronal section of the nose this opening is seen to be placed near the roof of the sinus (fig. 1011). An accessory opening of the maxillary sinus is frequently present below and behind the hiatus semilunaris. The *inferior meatus* is below and lateral to the inferior nasal concha; the nasolacrimal duct opens into this meatus under cover of the anterior part of the inferior concha.

The medial wall or nasal septum (fig. 1005).—The nasal septum is frequently more or less deflected from the median plane, thus lessening the size of one half of the nasal cavity and increasing that of the other; ridges or spurs of bone sometimes project from the septum to one or other side. Immediately over the incisive canal at the lower edge of the cartilage of the septum a depression is sometimes seen; it points downwards and forwards, and occupies the position of a canal which connected the nasal with the buccal cavity in early fetal life. On each side of the septum close to this recess a minute orifice may be discerned; it leads backwards into a blind tubular pouch, 2 to 6 mm. long—the vestigial *vomer nasal organ*—which is supported by a strip of cartilage named the *vomer nasal cartilage*; it is lined by epithelium consisting mainly of a single layer of tall columnar cells and contains many glands. This organ is well developed in many of the lower animals (e.g. reptiles*), where it apparently plays a part in the sense of smell, since it is supplied by twigs of the olfactory nerve and is lined with epithelium similar to that in the olfactory region of the nose.

The **roof** of the nasal cavity is narrow from side to side, except at its posterior part, and may be divided, from behind forwards, into sphenoidal, ethmoidal and frontonasal parts, corresponding to the bones which enter into its formation (pp. 299 and 302). The ethmoidal part is almost horizontal, but the frontonasal and sphenoidal parts slope downwards and forwards and downwards and backwards, respectively. The cavity is therefore deepest where its roof is formed by the cribriform plate of the ethmoid bone.

The **floor** is concave from side to side, flat and almost horizontal antero-posteriorly; its anterior three-fourths are formed by the palatine process of the maxilla, its posterior one-fourth by the horizontal part of the palatine bone. About 2 cm. behind the anterior end of the floor a slight depression in the mucous membrane overlies the incisive canal (p. 345).

The **nasal mucous membrane** lines the nasal cavities with the exception of the vestibules, and is intimately adherent to the periosteum or perichondrium. It is continuous with the mucous membrane of the nasal part of the pharynx through the posterior nasal apertures; with the conjunctiva, through the nasolacrimal duct and lacrimal canaliculi; and with the mucous membranes of the sphenoidal, ethmoidal, frontal and maxillary sinuses, through the openings of these sinuses.

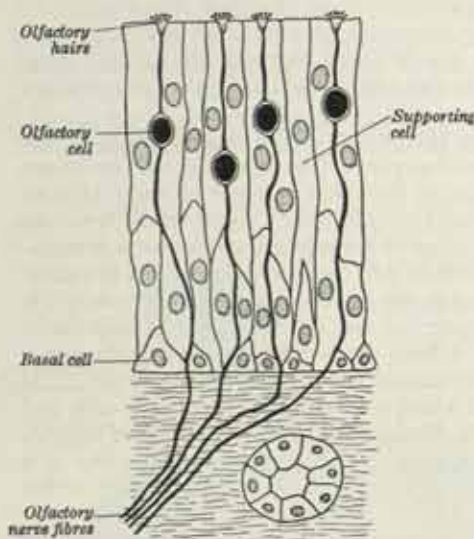
The mucous membrane is thickest and most vascular over the nasal conchæ, especially at their extremities. It is also thick over the nasal septum, but very thin in the meatuses, on the floor of the nasal cavity, and in the various sinuses. The thickness of the membrane reduces materially the size of the bony cavity and the apertures communicating with it.

Structure of the mucous membrane.—The epithelium of the mucous membrane differs in its characteristics according to the functions of the part of the nose in which it is found. In the *respiratory region* it is columnar and ciliated. Goblet or mucous cells are interspersed among the columnar cells, while smaller pyramidal cells are found between the bases of the latter. Beneath the epithelium and its basement-membrane there is a fibrous layer infiltrated with lymphocytes, forming in many parts a diffuse lymphoid tissue, and under this a nearly continuous layer of mucous and serous glands, the ducts of which open upon the surface. The abundant amount of mucus secreted by the glands and goblet cells makes the surface

* A. d'A. Bellairs, *J. Anat.*, 76, 167, 1942; A. d'A. Bellairs and J. D. Boyd, *Proc. Zool. Soc.*, Lond., 120, 269, 1950.

of the mucosa moist and sticky. Because of this the dust in the inspired air is deposited on the surface and the air is moistened. The vascularity of the membrane ensures warming of the inspired air. The contaminated mucus film covering the membrane is moved by ciliary action downward and backward, away from the olfactory region and into the nasopharynx. Palate movements then transfer it to the oral pharynx and it is swallowed. In the *olfactory region*, which extends over the upper 10 mm. or

FIG. 1009.—A scheme of the olfactory mucous membrane.*



process of the cell is frequently beaded and is continued as an olfactory nerve-fibre (p. 1093). Beneath the epithelium, and extending through the thickness of the mucous membrane, there is a layer of branched, tubular, serous glands (the *nasal glands*), which are rich in enzymes (acid phosphatase, esterase, lipase). Their ducts pass between the supporting cells to open on the surface. The gases responsible for odours dissolve in the fluid secretion of the glands and thus stimulate the olfactory hairs.

Vessels and Nerves.—The *arteries* of the nasal cavity are the anterior and posterior ethmoidal branches of the ophthalmic artery, which supply the ethmoidal and frontal sinuses, and the roof of the nose; the sphenopalatine branch of the maxillary artery, which supplies the mucous membrane covering the conchæ, the meatuses, and septum; the terminal part of the greater palatine artery which ascends through the incisive canal (p. 750); the septal ramus of the superior labial branch of the facial artery, which supplies the part of the septum in the region of the vestibule, anastomosing with the sphenopalatine artery, and is a common site of bleeding from the nose (epistaxis); the infra-orbital and inferior alveolar branches of the maxillary artery which supply the lining membrane of the maxillary sinus; and the pharyngeal branch of the same artery, which is distributed to the sphenoidal sinus. The ramifications of these vessels form a close plexiform network, beneath and in the substance of the mucous membrane.

The *veins* form a close cavernous plexus beneath the mucous membrane. Arterio-venous communications have been described.† The plexus is especially marked over the lower part of the septum and over the middle and inferior conchæ. Some of the veins open into the sphenopalatine vein; others join the facial vein; some accompany the ethmoidal arteries, and end in the ophthalmic veins; a few communicate with the veins on the orbital surface of the frontal lobe of the brain, through the foramina in the cribriform plate of the ethmoid bone. When the foramen cæcum is patent it transmits a vein from the nasal cavity to the superior sagittal sinus.

The *lymph vessels* are described on p. 888.

The *nerves of ordinary sensation* (figs. 936, 1010) that supply the nasal cavity are: the anterior ethmoidal branch of the nasociliary nerve which supplies the anterior and upper part of the septum, the anterior part of the roof and the anterior parts of the middle and inferior conchæ with the lateral wall in front of these; the infraorbital nerve

* From a description by W. E. Le Gros Clark and R. T. Turner Warwick, *Jour. Neur., Neuro-surg. and Psychiatry*, 9, 1946.

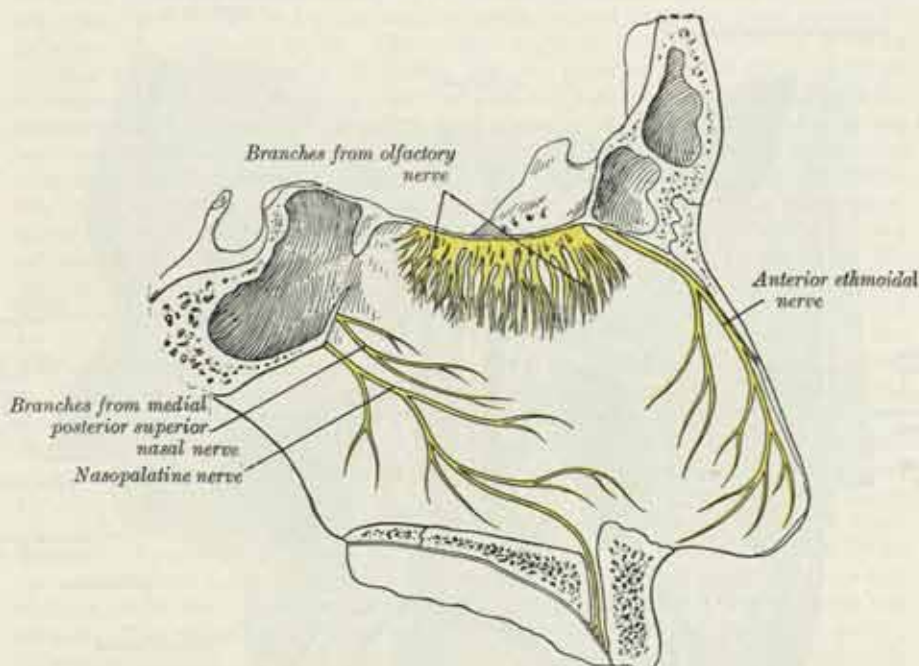
† J. F. Harper, *Proc. Anat. Soc. J. Anat.*, 81, 1947.

so of the septum and over the superior concha and the lateral wall above it, the mucous membrane is yellowish in colour, and the epithelial cells are of three types, supporting (sustentacular) cells, basal cells and olfactory cells proper (fig. 1009). The *supporting cells* are tall, nonciliated, cylindrical cells, their oval nuclei lie in approximately the same plane about the middle of the cells, and the deep parts of the cells taper as they extend to the basement membrane. The cytoplasm contains a yellowish-brown pigment. The *basal cells* are pyramidal in shape and contain enzymes (phosphatases and esterase). The *olfactory cells* are bipolar nerve cells, the cell bodies and spherical nuclei of which lie between the supporting cells a little deep to the plane of the oval nuclei of the latter. The superficial process of each cell runs between the supporting cells and ends at the surface of the mucous membrane in a cup-like expansion, from the edge of which there arise one or more fine hair-like processes, called the *olfactory hairs*. The deep

which supplies the vestibule; the anterior superior alveolar nerve which supplies the part of the septum and floor near the anterior nasal spine and the anterior part of the lateral wall as high as the opening of the maxillary sinus; the lateral posterior superior nasal and the medial posterior superior nasal nerves (including the nasopalatine nerve), which are branches of the pterygopalatine ganglion, and the posterior inferior nasal branches of the anterior palatine nerve, supply the posterior three-quarters of the lateral wall, roof, floor and septum; branches from the nerve of the pterygoid canal which supply the upper and back part of the roof and septum. It is to be noted that, with the exception of the nasociliary nerve, all the nerves supplying the nasal cavity are derived from the maxillary division of the trigeminal nerve.

The *olfactory nerves* are distributed to the olfactory region. Their fibres arise from the bipolar olfactory cells and are destitute of medullary sheaths. They unite in

FIG. 1010.—The nerves of the right side of the septum of the nose.



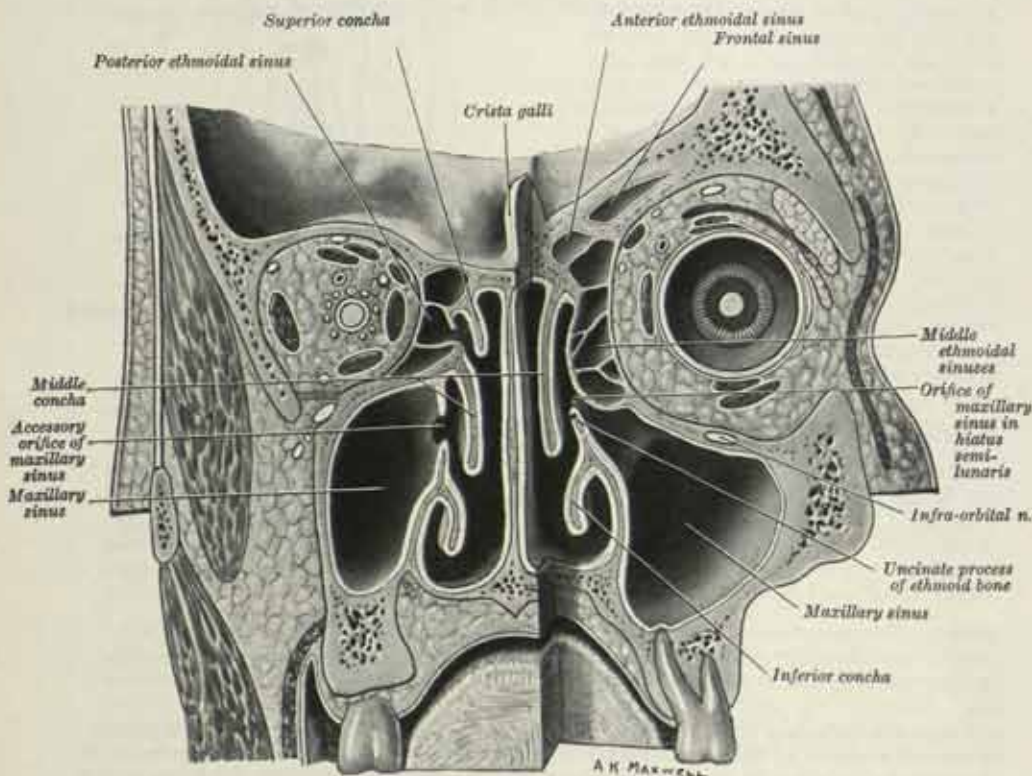
fasciculi which cross one another in various directions, and thus give rise to the appearance of a plexus in the mucous membrane (fig. 1010) and then ascend in grooves or canals in the ethmoid bone; they pass into the skull through the foramina in the cribriform plate of the ethmoid and enter the under surface of the olfactory bulbs, in which they ramify and form synapses with the dendrites of the mitral cells (fig. 927). Closely associated with the olfactory nerves are the *nervi terminales* (p. 1093).

THE PARANASAL SINUSES (figs. 1006, 1007, 1008, 1011)

The **paranasal sinuses** are the frontal, ethmoidal, sphenoidal and maxillary; they vary in size and form in different individuals, and are lined with mucous membrane continuous with that of the nasal cavity. The mucous membrane resembles that of the respiratory region of the nasal cavity, but is thinner, less vascular and more loosely adherent to the bony walls of the sinuses. The mucus secreted by the glands in the mucous membrane is swept into the nose through the apertures of the sinuses by the movement of the cilia covering the surface. The cilia are not found uniformly in the lining mucous membrane but are always present near the opening into the nasal cavity. The function of the sinuses is doubtful. They lighten the skull and add resonance to the voice. They vary considerably in size in different individuals. Some are rudimentary, or even absent, at birth; they enlarge appreciably during the time of eruption of the permanent teeth and after puberty and this growth is a factor in the alteration in the size and shape of the face at these times.

The **frontal sinuses**, two in number, are situated behind the superciliary arches, between the outer and inner tables of the frontal bone. When of average size, they underlie a triangular area on the surface the angles of which are formed by the nasion, a point about 3 cm. above the nasion and the junction of the medial third with the rest of the supra-orbital margin (fig. 1012). They are rarely symmetrical, because the septum between them frequently deviates from the median plane. Their average measurements are as follows: height, 3.16 cm.; breadth, 2.58 cm.;

FIG. 1011.—A coronal section through the nasal cavity, viewed from behind. On the left side the plane of the section is more posterior. The normal orifice of the maxillary sinus is shown on the right side, and the not uncommon accessory orifice on the left side.



depth from before backwards, 1.8 cm. Each extends upwards above the medial part of the eyebrow and backwards into the medial part of the roof of the orbit. The frontal sinus is sometimes divided into a number of intercommunicating recesses by incomplete bony partitions. Rarely, one or both sinuses may be absent, and the degree of prominence of the superciliary arches is no indication of the presence or size of the frontal sinuses. The part of the sinus extending upwards in the frontal bone may be small and the orbital part large, or vice versa. Sometimes one sinus may overlap in front of the other. Each opens into the anterior part of the corresponding middle meatus of the nose either through the ethmoidal infundibulum or through the frontonasal duct, which traverses the anterior part of the labyrinth of the ethmoid. Rudimentary or absent at birth, they are generally fairly well developed between the seventh and eighth years, but reach their full size only after puberty (see also p. 332). The arterial blood supply of the sinus is from the supraorbital artery and the venous drainage is into the anastomotic vein in the supraorbital notch connecting the supraorbital and superior ophthalmic veins. The lymph drainage is to the submandibular nodes. The nerve supply is derived from the supraorbital nerve.

The **ethmoidal sinuses** (see pp. 334-336) consist of thin-walled cavities in the ethmoidal labyrinth, completed by the frontal, maxillary, lacrimal, sphenoidal

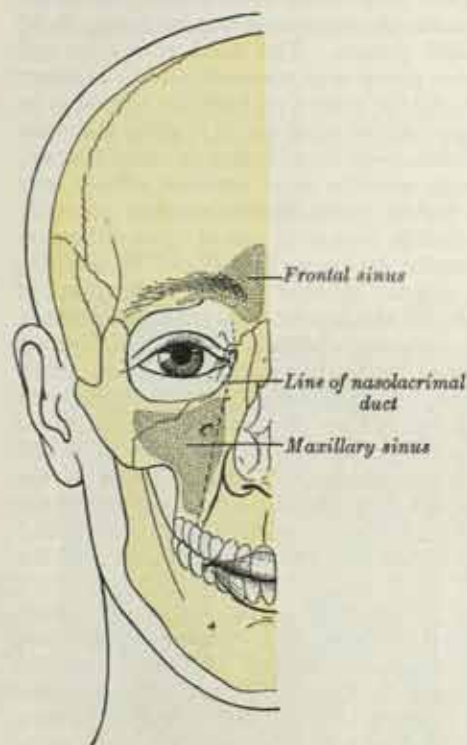
and palatine bones. They vary in number and size from 3 large to 18 small sinuses and their openings into the nasal cavity are very variable. They lie between the upper parts of the nasal cavity and the orbits, and are separated from the latter by the extremely thin orbital plates of the ethmoid; infection may spread from the sinuses into the orbit and produce orbital cellulitis. On each side they are arranged in three groups—*anterior*, *middle*, and *posterior*, though some anatomists divide them into two groups, *anterior* and *posterior*, the *anterior* group including those described below as the *anterior* and *middle* groups. The three groups are not sharply delimited from each other and one group may encroach on the territory generally occupied by another. In each group the sinuses are partially separated by incomplete bony septa. The *anterior* group vary up to eleven in number and open into the ethmoidal infundibulum or the frontonasal duct by one or more orifices; one sinus frequently lies in the *agger nasi* and the most *anterior* sinuses may encroach upon the *frontal sinus*. The *middle* group (*bullar sinuses*) generally comprise three sinuses and open into the *middle meatus* by one or more orifices on or above the ethmoidal bulla. The *posterior* group vary from one to seven in number and usually open by one orifice into the *superior meatus* under cover of the *superior concha*, though one may open into the *highest meatus* (when present), and one or more sometimes open into the *sphenoidal sinus*. The *posterior* group are very closely related to the *optic canal* and *optic nerve*. The ethmoidal sinuses are small, but of clinical importance, at birth; they grow rapidly between the sixth and eighth years and after puberty. They derive their arterial blood supply from the *sphenopalatine* (p. 750), *anterior ethmoidal* and *posterior ethmoidal* arteries and are drained by the corresponding veins. The lymphatics of the *anterior* and *middle* groups drain into the *sub-mandibular* nodes and those of the *posterior* group into the *retropharyngeal* nodes. The ethmoidal sinuses are supplied by the *anterior* and *posterior ethmoidal* nerves and the orbital branches of the *pterygopalatine ganglion*.

The **sphenoidal sinuses** (see pp. 315, 316), two in number, are placed behind the upper part of the nasal cavity. Contained within the body of the *sphenoid bone*, they are, therefore, related, above, to the *optic chiasma*, and the *hypophysis cerebri*; on each side, to the *internal carotid artery* and the *cavernous sinus*. If the sinuses are small, they lie in front of the *hypophysis cerebri*. They vary in size and shape, and, owing to the lateral displacement of the intervening septum, are rarely symmetrical. Frequently one sinus is much the larger of the two and extends across the median plane behind the sinus of the opposite side; occasionally one sinus may overlap above the other, and rarely there is a communication between the two sinuses. The following are their average measurements: vertical height, 2 cm.; transverse breadth, 1.8 cm.; anteroposterior depth, 2.1 cm. When exceptionally large they may extend into the roots of the *pterygoid processes* or *greater wings*, and may invade the *basilar part* of the *occipital bone*. Occasionally there are gaps in the bony walls and the mucous membrane may lie directly against the *dura mater*. Bony ridges, produced by the *internal carotid artery* and the *pterygoid canal*, may project into the sinuses from the lateral walls and floor respectively. A *posterior ethmoidal sinus* may extend into the body of the *sphenoid* and largely replace a *sphenoidal sinus*. Each sinus communicates with the *spheno-ethmoidal recess* by an aperture in the upper part of its *anterior wall*. They are present as minute cavities at birth, but their main development takes place after puberty. Their blood supply is by means of the *posterior ethmoidal vessels* and the lymph drainage is to the *retropharyngeal* nodes. Their nerve-supply is from the *posterior ethmoidal nerves* and the orbital branches of the *pterygopalatine ganglion*.

The **maxillary sinuses**, which are the largest accessory air-sinuses of the nose, are pyramidal cavities in the bodies of the *maxillæ* (fig. 1011 and Pl. IV, fig. 2). The base of each is formed by the lateral wall of the nasal cavity; the apex extends into the *zygomatic process* of the *maxilla*. The roof or orbital wall is frequently ridged by the *infra-orbital canal*, while the floor is formed by the *alveolar process* and is usually about 1.25 cm. below the level of the floor of the nose on a line drawn laterally from the lower border of the *ala*; several conical elevations corresponding with the roots of the first and second molar teeth project into the floor, which is sometimes perforated by one or more of these roots. Sometimes the roots of the first and second premolars and the third molar, and occasionally the root of the

canine, also project into the sinus. The size of the maxillary sinus varies in different skulls, and even on the two sides of the same skull; when large, its apex may invade the zygomatic bone. The

FIG. 1012.—An outline of the bones of the face, showing the positions of the frontal and maxillary sinuses.



following measurements are those of an average-sized air-sinus: vertical height opposite the first molar tooth, 3.5 cm.; transverse breadth, 2.5 cm.; anteroposterior depth, 3.2 cm. It communicates with the lower part of the hiatus semilunaris through an opening in the anterosuperior part of its base (fig. 1011); a second orifice is frequently seen in, or immediately below, the hiatus. The maxillary sinus appears as a shallow groove on the medial surface of the bone about the fourth month of intrauterine life, but does not reach its full size until after the eruption of all the permanent teeth.* The blood supply of the sinus is by means of the facial, infraorbital and greater palatine vessels; the lymph drainage is to the submandibular nodes. The nerve supply is derived from the infraorbital and the anterior, middle and posterior superior alveolar nerves.

Radiology. Normal sinuses are radiolucent whereas diseased sinuses show varying degrees of opacity. Radiographs also reveal the extent of development of the sinuses. In anteroposterior view (Plate IV, fig. 2, and Plate XXII), the sinuses appear as follows. The frontal sinuses are seen above the nasal cavity and the medial

part of the orbits and their asymmetry, vertical extent and the presence of bony septa can be assessed. The ethmoidal sinuses are superimposed on each other as well as on the sphenoidal sinus in the radiograph; they lie between the orbits, below the shadow of the cribriform plate. The sphenoidal sinus is not clear in this view. The maxillary sinus forms a pyramidal-shaped translucent area below the orbit and lateral to the lower part of the nasal cavity; inferiorly it extends into the alveolar process of the maxilla. In lateral view (Plate III and Plate XXI), the extent of the frontal sinus both upwards into the frontal bone and backwards into the orbital roof can be seen. The ethmoidal sinuses are seen extending from the shadow of the frontal process of the maxilla as far back as the sphenoidal sinus, the latter being clear and distinct below and in front of the fossa for the hypophysis, though of course the areas of the two sphenoidal sinuses are superimposed, and the individual sphenoidal sinuses are best seen in a superior view. The maxillary sinus is well seen in a lateral view; it lies below the orbit and its extent in relation to the roots of the teeth can be clearly seen.

The maxillary and frontal sinuses can also be examined by the method of transillumination. In a dark room an electric torch is placed in the mouth, in the case of the maxillary sinus, or against the upper medial angle of the front of the orbit, for the frontal sinus. Normally, a red glow is seen in the region of these sinuses, which may be absent in cases where they are diseased.

Applied Anatomy.—Congenital deformities of the nose occur occasionally, such as complete absence of the external nose, an aperture only being present, or perfect development on one side, and suppression or malformation on the other.

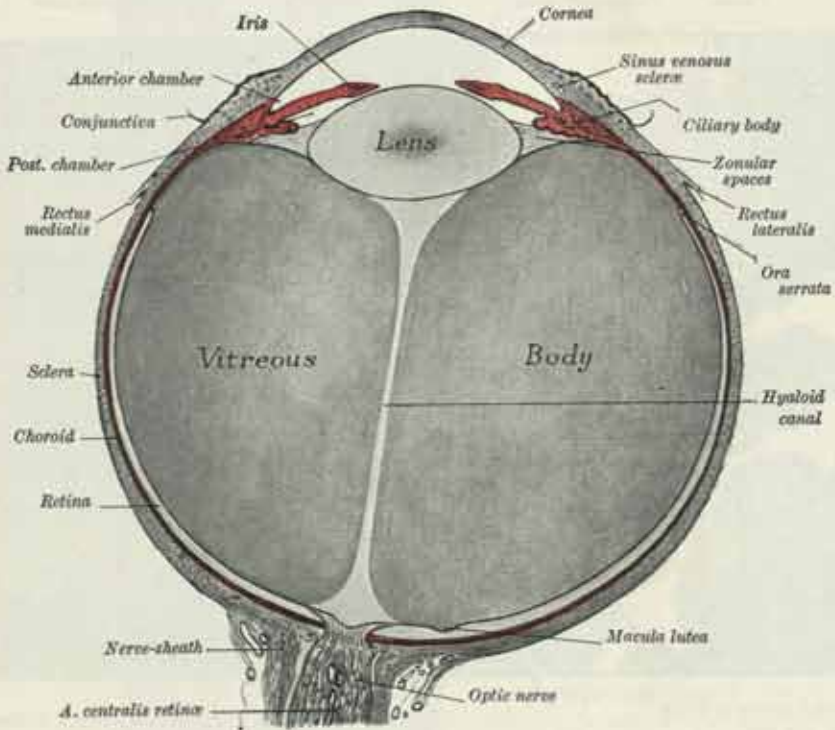
The septum of the nose may be displaced or may deviate from the median plane as a result of an injury or of some congenital defect. Sometimes the deviation may be

* The measurements of the paranasal sinuses supplied in the text are those given by A. Logan Turner, *Accessory Sinuses of the Nose*, 1901.

so great that the septum may come into contact with the lateral wall of the nasal cavity, producing complete unilateral obstruction. Submucous resection of the septum is sometimes necessary in this condition. The marginal parts of the septum must be left or depression of the bridge of the nose will result.

Suppuration in the paranasal sinuses is of frequent occurrence, and in connexion with this it is of importance to notice that the middle meatus is of such a form that pus running down from the frontal sinus or the anterior ethmoidal sinuses is directed by the hiatus semilunaris into the opening of the maxillary sinus, so that the latter sinus may, in some cases, act as a secondary reservoir for pus discharged from these sinuses. All the paranasal sinuses can be infected from the nasal cavity, but it should be noted that in the case of the maxillary sinus, the infection is occasionally conveyed in another way, and that is from the teeth (p. 1373). This sinus is the one most frequently the

FIG. 1013.—A horizontal section through the eyeball. (Human.) (After Sobotta.)



seat of chronic suppuration, in which case the cilia are often lost over the surface of the mucosa so that it requires drainage. The normal opening of the sinus is high above the floor and is thus poorly placed for natural drainage. Surgical drainage is thus effected by puncturing the lateral wall of the inferior nasal meatus or the canine fossa on the anterior surface of the maxilla.

THE ORGAN OF SIGHT

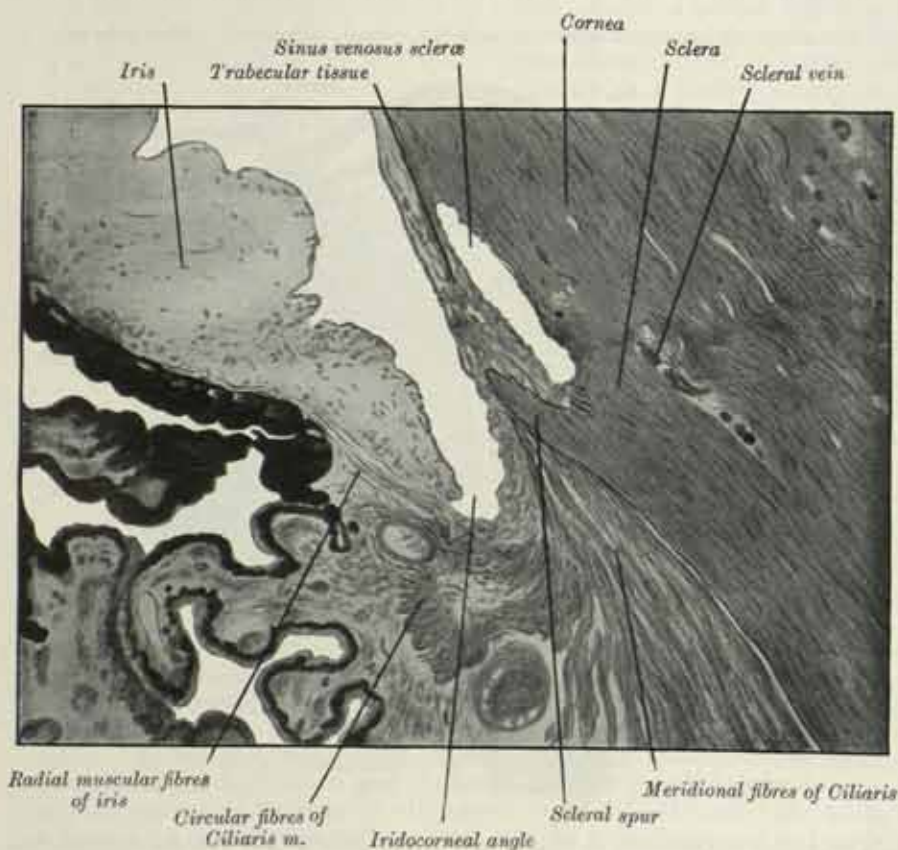
The eyeball is the peripheral organ of sight, and is situated in the cavity of the orbit, the walls of which serve to protect it from injury. Certain accessory structures, viz. the muscles, fasciæ, eyebrows, eyelids, conjunctiva and lacrimal apparatus, are intimately associated with the eyeball and will be described in this section.

The eyeball is imbedded in the fat of the orbit, but is separated from it by a thin membranous sac, termed the *fascial sheath of the eyeball* (p. 1254). It is composed of segments of two spheres of different sizes. The anterior segment is one of a small sphere; it is transparent, and it forms about one-sixth of the eyeball. It is more prominent than the posterior segment, which is one of a larger sphere, and is opaque, and forms about five-sixths of the whole circumference of the eyeball. The term *anterior pole* is applied to the central point of the anterior curvature of the eyeball, and that of *posterior pole* to the central point of its posterior curvature; a line

joining the two poles forms the *optic axis*. The axes of the two eyeballs are nearly parallel, and therefore do not correspond with the axes of the orbits which are directed forwards and laterally. The optic nerves follow the direction of the axes of the orbits, and therefore are not parallel; *each nerve enters its eyeball 3 mm. to the nasal side of the posterior pole*. The vertical diameter (23.5 mm.) of the eyeball is rather less than the transverse and anteroposterior diameters (24 mm.); the anteroposterior diameter at birth is about 17.5 mm. and at puberty from 20 to 21 mm. In the female all three diameters are rather less than in the male.

The eyeball comprises three coats, and the contents enclosed by these coats.

FIG. 1014.—A general view of the iridocorneal angle. Enlarged. (After Thomson.)



THE COATS OF THE EYE (fig. 1013)

From without inwards the three coats are : (1) the fibrous coat, consisting of the *sclera* behind and the *cornea* in front ; (2) the vascular, pigmented coat, comprising, from behind forwards, the *choroid*, *ciliary body* and *iris* ; and (3) the nervous coat, termed the *retina*.

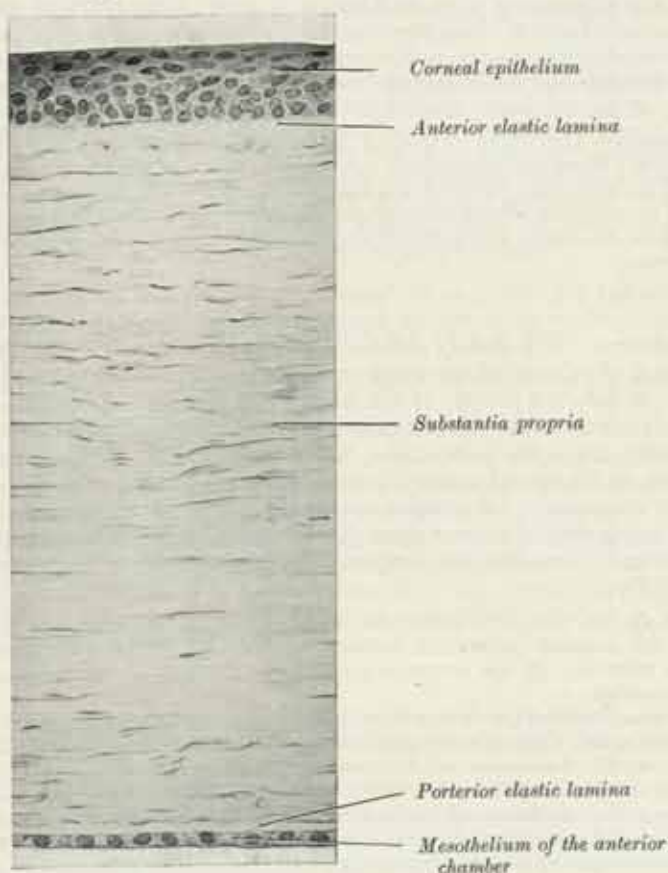
I. THE FIBROUS COAT

The fibrous coat of the eyeball (fig. 1013) consists of an opaque, posterior part, named the *sclera*, and a transparent, anterior part, named the *cornea*.

The *sclera*, so named from its density and hardness, is a firm membrane which serves to maintain the form of the eyeball. It is thickest (about 1 mm.) behind, near the entrance of the optic nerve, and thinnest (0.4 mm.) at a distance of about 6 mm. behind the sclerocorneal junction, in the region of insertion of the Recti muscles (p. 1252). Its *external surface* is white, and is in contact with the inner surface of the fascial sheath of the eyeball (p. 1254) ; it is smooth, except where the tendons of the orbital muscles are inserted into it ; its anterior part is covered by the

conjunctival membrane, reflected on to it from the deep surfaces of the eyelids and continuous anteriorly with that covering the cornea. Its *inner surface* is brown, and is marked by grooves in which the ciliary nerves and vessels are lodged; it is separated from the outer surface of the choroid by an extensive *perichoroidal space*, which is traversed by an exceedingly delicate cellular tissue, termed the *supra-choroid lamina* (or *lamina fusca of the sclera*). Behind, the sclera is pierced by the optic nerve, and is continuous through the fibrous sheath of this nerve with the dura mater. Where the optic nerve pierces the sclera, the latter has the appearance

FIG. 1015.—Vertical section through the human cornea. $\times 128$



of a cribriform plate and is named the *lamina cribrosa sclerae* (fig. 1021); the minute orifices in this lamina serve for the transmission of the nerve-bundles, and the fibrous septa between the orifices are continuous with the supporting tissue of the nerve. One opening, larger than the rest, and occupying the centre of the lamina, transmits the central artery and vein of the retina. The lamina cribrosa is the weakest part of the sclera; if the intra-ocular pressure be raised for some time, as in cases of chronic glaucoma, the lamina cribrosa becomes bulged outwards, producing the condition of 'cupped disc'. Around the lamina cribrosa sclerae numerous small apertures are present for the transmission of the ciliary vessels and nerves, and about midway between these and the sclerocorneal junction there are four or five large apertures for the transmission of veins [*venae vorticosae*]. In front, the sclera is directly continuous with the cornea, the line of union being termed the *sclerocorneal junction*. In the substance of the sclera close to this junction is a canal lined with endothelium running circularly round the eyeball, termed the *sinus venosus sclerae*. In a meridional section through the sclero-corneal junction (fig. 1014) this sinus presents the appearance of an oval cleft. The outer wall of the cleft is formed by a groove in the sclera. Posteriorly the cleft extends as far as a projecting rim of scleral tissue termed the *scleral spur* which in section is tri-

angular in form with the apex directed forwards and medially. The sinus may be double in parts of its course. The medial wall of the scleral sinus is formed by a loose trabecular tissue continuous anteriorly with the posterior elastic lamina of the cornea. Between the fibres of this tissue are spaces through which the aqueous humour in the anterior chamber filters into the sinus, from which it then passes into the bloodstream as the scleral sinus drains laterally into the anterior ciliary veins. Normally the sinus contains no blood; although the communicating channels between the sinus and the anterior ciliary veins contain no valves, these channels are oblique and flattened and prevent reflux of blood into the sinus, but under conditions of venous congestion blood may pass into the sinus. Antero-laterally, the scleral spur gives attachment to most of the fibres of the trabecular tissue mentioned above, whilst posteromedially it gives attachment to the meridional fibres of the Ciliaris muscle. The *iridocorneal angle* (fig. 1014) of the anterior chamber lies between the trabecular tissue and scleral spur anterolaterally, and the periphery of the iris posteromedially.

Structure.—The sclera is formed of white fibrous tissue intermixed with fine elastic fibres; flattened connective tissue cells, some of which are pigmented, are contained in cell-spaces between the fibres. The fibres are aggregated into bundles, which are arranged chiefly in an anteroposterior direction. Its *vessels* are very scanty; its capillaries are small, and unite at wide intervals. Its *nerves* are derived from the ciliary nerves.

The **cornea** (fig. 1013) is the anterior, projecting and transparent part of the external coat, which performs the major part of the refraction of the rays of light entering the eye. It is convex anteriorly, and projects as a flattened dome in front of the sclera. Its degree of curvature varies in different individuals, and in the same individual at different periods of life, being more pronounced in youth than in old age. As the curvature of the cornea is greater than that of the rest of the eyeball, a slight furrow, called the *sulcus sclerae*, lies at the junction of the cornea and sclera. The cornea is dense and about 1.2 mm. thick round its periphery and slightly thinner at its centre. Its anterior surface is somewhat elliptical, the transverse diameter being slightly greater than the vertical. Its posterior surface is circular and, because the corneoscleral junction is slightly oblique, is more extensive than the anterior surface.

Structure (fig. 1015).—The cornea consists from before backwards of four layers, viz.: (1) the corneal epithelium, continuous with that of the conjunctiva; (2) the substantia propria; (3) the posterior elastic lamina; and (4) the mesothelium of the anterior chamber.

The *corneal epithelium* covers the front of the cornea and generally consists of five layers of cells. The deepest cells are columnar; their basal surfaces are flat and their outer surfaces rounded and they contain large round or oval nuclei. The cells of the second layer are polyhedral, with oval nuclei. In the superficial layers the cells become progressively flattened, but, unlike the superficial cells of the epidermis, they contain flattened nuclei and they do not normally become keratinised. Most of the cells of the corneal epithelium are prickly-cells, similar to those of the germinative zone of the epidermis (p. 1296). At the sclerocorneal junction (or limbus), the epithelium becomes thicker (up to ten or more layers of cells) and is continuous with the conjunctiva covering the front part of the sclera (p. 1260).

The *substantia propria* is fibrous, tough, unyielding and perfectly transparent. It is composed of about sixty flattened, superimposed lamellae. These lamellae are made up of bundles of modified connective tissue, the fibres of which are continuous with those of the sclera. The fibres of each lamella are for the most part parallel with one another, but at right angles to those of adjacent lamellae. Fibres, however, frequently pass from one lamella to the next.

Between the lamellae there is a small amount of ground-substance, in which spaces are found, which are termed the *corneal spaces*. These are stellate in shape and communicate with one another by numerous offsets. Each contains a cell, named the *corneal corpuscle*, resembling in form the space in which it is lodged, but not entirely filling it.

The layer immediately beneath the corneal epithelium presents certain characteristics which have led some anatomists to regard it as a distinct membrane, and it has been named the *anterior elastic lamina*. It consists of extremely closely interwoven fibrils, similar to those found in the substantia propria, but contains no corneal corpuscles.

The *posterior elastic lamina* covers the posterior surface of the substantia propria, and is a thin, elastic, transparent, homogeneous membrane. When stripped from the substantia propria it curls up, and rolls upon itself, with the attached surface innermost.

At the margin of the cornea the posterior elastic lamina breaks up into fibres which form the trabecular tissue on the inner wall of the sinus venosus scleræ (p. 1238); the spaces between the trabeculæ are termed the *spaces of the iridocorneal angle*; they communicate with the sinus venosus scleræ and with the anterior chamber. Some of the fibres of this trabecular tissue pass on to the internal surface of the scleral spur and are continued into the substance of the iris, forming the *pectinate ligament of the iris*; others are connected with the sloping external surface of the scleral spur and a few reach the anterior part of the choroid.

The *mesothelium of the anterior chamber* covers the posterior surface of the posterior elastic lamina, is reflected on to the front of the iris, and also lines the spaces of the iridocorneal angle; it consists of a layer of polygonal, flattened, nucleated cells.

Vessels and Nerves.—The cornea is a non-vascular structure, the capillary vessels of the conjunctiva and sclera ending in loops at its circumference. Lymph vessels have not yet been demonstrated in it, but are probably represented by the channels in which the nerves run; these channels are lined by an endothelium. The *nerves* (see also p. 924) are numerous and are branches of the ophthalmic nerve derived from the ciliary nerves. Around the periphery of the cornea they form an *annular plexus*, from which fibres enter the substantia propria. They lose their medullary sheaths and ramify throughout the substantia propria in a delicate network, and their terminal filaments form a firm and closer plexus beneath the corneal epithelium. This is termed the *subepithelial plexus*, and from it fine, varicose fibrils are given off which ramify between the epithelial cells, forming an *intra-epithelial plexus*.

II. THE VASCULAR COAT (figs. 1013 and 1016 to 1019)

The vascular coat (or uveal tract) of the eye is formed from behind forwards by the choroid, the ciliary body and the iris.

The choroid covers the inner surface of the sclera, and extends as far forwards as the ora serrata of the retina. The ciliary body connects the anterior edge of the choroid with the circumference of the iris. The iris is a circular diaphragm behind the cornea, and presents near its centre the rounded aperture of the *pupil*.

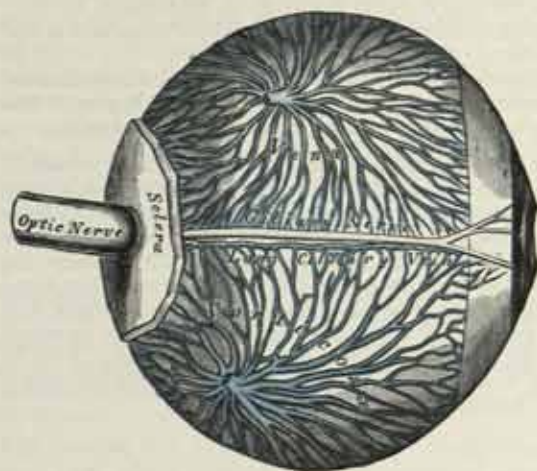
The **choroid** is a thin, highly vascular membrane, of a dark brown or chocolate colour, lining the posterior five-sixths of the eyeball; it is pierced behind by the optic nerve, and in this situation is firmly adherent to the sclera. It is thicker behind than in front. Its outer surface is loosely connected with the sclera by the suprachoroid lamina (or lamina fusca of the sclera); its inner surface is attached to the pigmented layer of the retina.

Structure.—The choroid consists mainly of a dense capillary plexus, and of small arteries and veins carrying blood to and from it. On its external surface is the thin membrane, termed the *suprachoroid lamina*, which is composed of delicate non-vascular lamellæ, each lamella consisting of a network of fine elastic fibres, among which are branched cells containing dark-brown pigment granules. The spaces between the lamellæ are lined by mesothelium, and open freely into the perichoroidal space, which, in its turn, communicates with the episcleral space at the points where the vessels and nerves are transmitted through holes in the sclera.

The *choroid proper* lies internal to this lamina. It consists of two layers: an outer, composed of small arteries and veins, with pigment-cells interspersed between them; and an inner, consisting of a capillary plexus. The outer layer or *vascular lamina* consists, in part, of the larger branches of the short posterior ciliary arteries, which run forwards between the veins before they bend inwards to end in the capillaries, but is formed principally of veins, named, from their arrangement, the *venæ vorticosæ* (fig. 1016); these converge to four or five equidistant trunks, which pierce the sclera about midway between the sclerocorneal junction and the entrance of the optic nerve. Interspersed between the vessels there are dark star-shaped, pigment-cells, the processes of which communicate with those of neighbouring cells, and form a delicate network or stroma, which loses its pigmentary character towards the inner surface of the choroid. The inner layer, or *choriocapillary lamina* (fig. 1018) consists of an exceedingly fine capillary plexus, formed by the short ciliary vessels; the network is closer and finer in the posterior than in the anterior part of the choroid. About 1.25 cm. behind the cornea its meshes become larger, and are continuous with those of the ciliary processes. These laminae are connected by a *stratum intermedium* consisting of fine elastic fibres. On the inner surface of the choriocapillary lamina is a very thin, structureless, or faintly fibrous membrane, called the *basal lamina*; it is closely connected with the stroma of the choroid, and separates it from the pigmented layer of the retina.

Tapetum.—In many animals the back part of the choroid presents the *tapetum*, which reflects light strongly giving a greenish iridescent appearance. It consists of several layers, either of cells or fibres, lying deep to the choriocapillary lamina.

FIG. 1016.—The veins of the choroid. (Enlarged.)



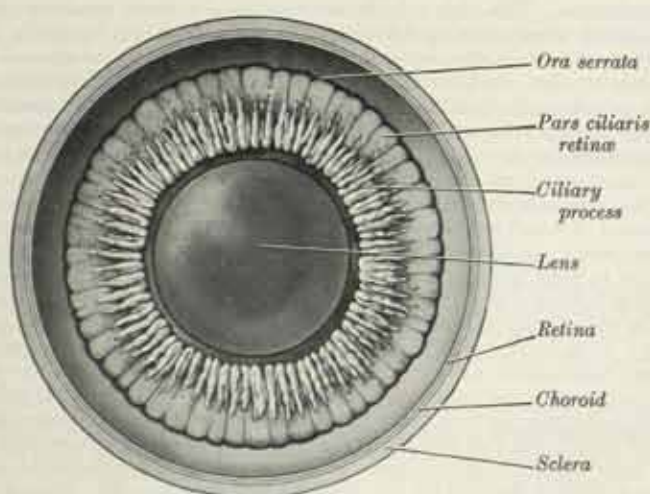
The **ciliary body** comprises the ciliary ring, the ciliary processes and the Ciliaris muscle.

The *ciliary ring* is a zone about 4 mm. in width, directly continuous with the anterior part of the choroid; it presents numerous ridges arranged in a radial manner, but has no choriocapillary lamina.

The *ciliary processes* are formed by the inward folding of the various layers of the choroid (i.e. the choroid proper and the basal lamina), and are received between corresponding foldings of the suspensory ligament of the lens. They are arranged in a circle, and form

a sort of frill behind the iris, round the margin of the lens (fig. 1017). They vary from sixty to eighty in number, lie side by side, and may be divided into large and small processes; the former are about 2.5 mm. long, and the latter, consisting of about one-third of the entire number, are situated in the spaces between them, but without regular alternation. Each is attached by its peripheral end to three or four of the ridges of the ciliary ring; the opposite extremity is free and rounded, and is directed towards the posterior chamber of the eyeball and circumference of the lens. In front, the ciliary processes are continuous with the periphery of the iris. Their posterior surfaces are connected with the suspensory ligament of the lens.

FIG. 1017.—The interior of the anterior half of the eyeball.



Structure.—The ciliary processes are similar in structure to the choroid but the vessels are larger and have chiefly a longitudinal direction. Their posterior surfaces are covered by the *ciliary part of the retina*, continued from the nervous part of the retina forwards beyond the ora serrata, and consisting of an outer layer of cubical pigment-cells, and an inner layer of columnar cells which are not pigmented. In the

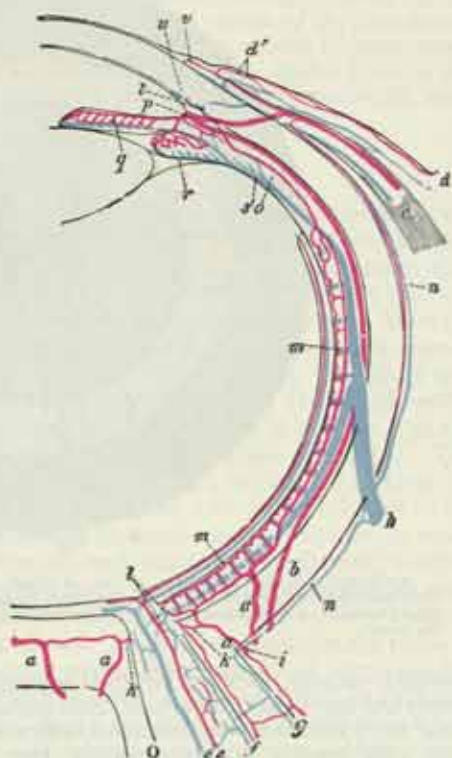
stroma of the ciliary processes there are also stellate pigment-cells, but these are not so numerous as in the choroid itself.

The *Ciliaris muscle* (fig. 1014) consists of unstriated fibres; it forms a greyish, semitransparent, circular band, about 6 mm. broad, on the outer surface of the fore-part of the choroid. It consists of meridional and circular fibres. The *meridional* fibres, much the more numerous, arise from the posterior margin of the scleral spur (p. 1237); they run backwards, and are attached to the ciliary processes and ring. The *circular* fibres are internal to the meridional ones, and in a meridional section appear as a triangular zone behind the iridocorneal angle and close to the circumference of the iris; they are well developed in hypermetropic, but are rudimentary or absent in myopic, eyes. The Ciliaris muscle is the chief agent in accommodation, i.e. in adjusting the eye to the vision of near objects. When it contracts, it draws forwards the ciliary processes, relaxes the suspensory ligament of the lens, and thus allows the lens, because of its inherent elasticity, to become more convex.

The *iris* has received its name from the various colours it presents in different individuals. It is a thin, circular, contractile disc, suspended in the aqueous humour between the cornea and the lens, and perforated a little to the nasal side of its centre by the circular aperture of the *pupil*. Its periphery is attached to the middle of the anterior surface of the ciliary body, and is also connected with the posterior elastic lamina of the cornea by means of the pectinate ligament; its flattened surfaces look forwards and backwards, the anterior towards the cornea, the posterior towards the ciliary processes and lens. The iris divides the space between the lens and the cornea into an anterior and a posterior chamber (fig. 1013). The *anterior chamber* of the eye is bounded in front by the posterior surface of the cornea, behind by the front of the iris, and, opposite the pupil, by the central part of the front of the lens. The part of this space between the peripheral part of the iris on the one hand and the scleral spur and trabecular tissue in the medial wall of the sinus venosus sclerae on the other is termed the *iridocorneal angle*. The *posterior chamber* is a narrow chink behind the iris, and in front of the lens and its suspensory ligament. In the adult the two chambers communicate through the pupil, but in the fetus up to the seventh month they are separated by the *pupillary membrane* (p. 1243).

The colour of the iris is produced by the reflection of light from dark pigment cells underlying a translucent tissue, and is therefore determined by the amount of the pigment and its distribution throughout the texture of the iris. The number and the situation of the pigment-cells differ in different irises. In the albino pigment is absent; in the various shades of blue eyes the pigment-cells are confined to the posterior surface of the iris, whereas in grey, brown, and black

FIG. 1018.—A diagrammatic representation of the course of the vessels of the eye. Horizontal section. (Leber.) Arteries and capillaries red; veins blue.



O. Entrance of optic nerve. a. Short posterior ciliary arteries. b. Long posterior ciliary arteries. c. Anterior ciliary vessels. d. Posterior conjunctival vessels. d'. Anterior conjunctival vessels. e. Central vessels of the retina. f. Vessels of the inner sheath of the optic nerve. g. Vessels of the outer sheath. h. Vorticosae veins. i. Short posterior ciliary vein. j. Branches of the short posterior ciliary arteries to the optic nerve. l. Anastomosis of choroidal vessels with those of optic nerve. m. Choriocapillary lamina. n. Episcleral vessels. o. Recurrent artery of the choroid. p. Circulus arteriosus major (in section). q. Vessels of iris. r. Vessels of ciliary process. s. Branch from ciliary muscle to vorticosae vein. t. Branch from ciliary muscle to anterior ciliary vein. u. Sinus venosus sclerae. v. Capillary loop at margin of cornea.

eyes pigment is found also in the cells of the stroma and in those of the mesothelium on the front of the iris.

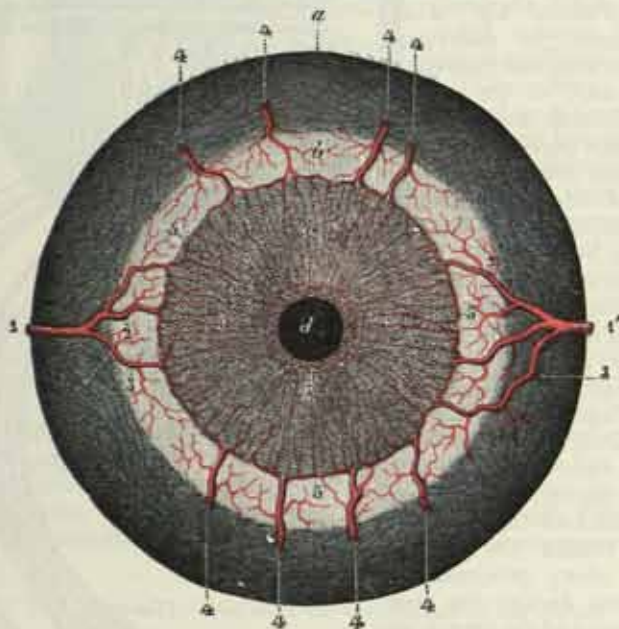
Structure.—The iris is composed of the following structures :

1. In the front there is a layer of flattened mesothelial cells, placed on a delicate hyaline basement-membrane.

This layer of cells is continuous with the mesothelium covering the posterior elastic lamina of the cornea, and in individuals with dark eyes the cells contain pigment-granules.

2. The *stroma* of the iris consists of connective tissue-fibres and cells. A few fibres at the circumference of the iris have a circular direction ; but the majority are

FIG. 1019.—The iris, viewed from in front, with its *circulus arteriosus major* and *circulus arteriosus minor*. (Testut.)



a, Choroid. b, Ciliary muscle. c, Iris. d, Pupil. 1 and 1'. The two long ciliary arteries with 2, their ascending branches of bifurcation ; 3, their descending branches of bifurcation. 4. The anterior ciliary arteries. 5. Circulus major ; 6, its branches radiating through the iris. 7. Circulus minor around the pupil.

arranged radially, forming, by their interlacement, delicate meshes, in which the vessels and nerves are contained. Interspersed between the bundles of connective tissue there are numerous branched cells with fine processes. In dark eyes many of these cells contain pigment-granules, but in blue eyes and the eyes of albinos they are unpigmented. The pigment cells are most numerous in the anterior part of the stroma.

3. The *muscular fibres* are involuntary, and consist of circular and radiating fibres. The *circular fibres* form the *Sphincter pupillæ* ; they are arranged in a band about 1 mm. wide which surrounds the margin of the pupil, towards the posterior surface of the iris ; those near the free margin of the band are closely aggregated ; those near the periphery are somewhat separated and form incomplete circles. The *radiating fibres* form the *Dilatator pupillæ* and lie close to the posterior surface of the iris ; they converge from the circumference towards the centre, and blend with the circular fibres near the margin of the pupil. The muscle fibres of both the *Dilatator* and the *Sphincter pupillæ* are derived from the cells of the outer layer of the optic cup, and are therefore *ectodermal* in origin.

4. The posterior surface of the iris is of a deep purple tint, being covered by two layers of pigmented epithelial cells, continuous at the periphery of the iris with the ciliary part of the retina. This pigmented epithelium is called the *iridial part of the retina* (p. 1243).

Vessels and Nerves.—The *arteries of the iris* are derived from the long posterior and the anterior ciliary arteries, and from the vessels of the ciliary processes. Each of the two long ciliary arteries, on reaching the attached margin of the iris, divides

into an upper and a lower branch ; these anastomose with corresponding branches of the artery from the opposite side and with the anterior ciliary arteries, and form a vascular circle (*circulus arteriosus major*). From this circle vessels converge to the free margin of the iris, and there communicate and form a second circle (*circulus arteriosus minor*) (fig. 1019).

The *nerves of the choroid and iris* are the long and short ciliary nerves ; the former are branches of the nasociliary nerve, the latter of the ciliary ganglion. They pierce the sclera around the entrance of the optic nerve, run forwards in the perichoroidal space, and supply the blood-vessels of the choroid and the Ciliary muscle. After reaching the iris they form a plexus around its attached margin ; from this are derived non-medullated fibres which end in the Sphincter and Dilatator pupillæ. Other fibres from the plexus end in a network on the anterior surface of the iris. The fibres derived through the motor (parasympathetic) root of the ciliary ganglion from the oculomotor nerve supply the Sphincter pupillæ and the Ciliaris muscle ; the sympathetic fibres in the long ciliary nerves supply the Dilatator pupillæ.

Membrana pupillaris.—In the fœtus, the pupil is closed by a delicate, vascular membrane, termed the *pupillary membrane* (p. 148). The vessels of this membrane are partly derived from those of the margin of the iris and partly from those of the capsule of the lens ; they end in loops a short distance from the centre of the membrane, which is thus left free from blood-vessels. About the sixth month of intrauterine life the membrane begins to disappear by absorption from the centre towards the circumference, and at birth only a few fragments are present ; in exceptional cases it persists.

III. THE RETINA (fig. 1013)

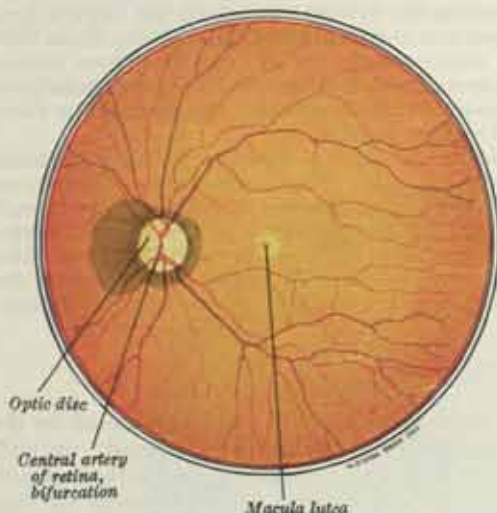
The **retina** is a delicate, nervous membrane, which is specially adapted for the reception of light stimuli. Its outer surface is in contact with the choroid ; its inner with the hyaloid membrane of the vitreous body. Posteriorly it is continuous with the optic nerve ; it gradually diminishes in thickness from behind forwards and, just behind the ciliary body, it presents a jagged margin named the *ora serrata*. Here the nervous tissues of the retina end, but a thin prolongation of the membrane extends forwards over the back of the ciliary processes and iris, forming the *ciliary and iridial parts of the retina*. This forward prolongation consists of the pigmented layer of the retina together with a deeper stratum of columnar epithelium ; in the iridial part of the retina both layers of epithelium are cubical and pigmented. The part of the retina extending from the optic disc to the ora serrata is known as the *optic part of the retina*. The retina is soft, translucent, and of a purple tint in the fresh state, owing to the presence of a colouring material, named *rhodopsin*, or *visual purple* ; but it soon becomes clouded, opaque, and bleached when exposed to light. Near the centre of the posterior part of the retina there is an oval, yellowish area, named the *macula lutea* (fig. 1020), where the visual sense is most perfect ; it shows a central depression, termed the *fovea centralis*. At the fovea centralis the retina is exceedingly thin, some of its layers having practically disappeared here, and the dark colour of the choroid is distinctly seen through it. About 3 mm. to the nasal side of the macula lutea the optic nerve pierces the retina at the *optic disc*, which has a diameter of about 1.5 mm. The circumference of the disc is slightly raised, while the central part presents a depression. The centre of the disc is pierced by the central artery and vein of the retina (fig. 1021). The optic disc is insensitive to light, and is termed the 'blind spot'. On ophthalmoscopic examination the normal disc is seen to be pink in colour due to the capillary vessels on its surface ; it is much paler than the retina. In cases of optic atrophy the capillary vessels disappear and the disc appears white. The name 'optic papilla' applied to the disc is misleading since the normal disc lies in the same plane as the surrounding retina.

Structure (figs. 1022, 1023).—The retina consists of an outer pigmented layer and an inner nervous stratum or retina proper. These layers are developed respectively from the outer and inner layers of the optic cup (p. 146).

The **pigmented layer** is a single stratum of cells. When viewed from the outer surface these cells are smooth and hexagonal in shape ; when seen in section each cell consists of an outer non-pigmented part containing a large oval nucleus, and an inner pigmented portion which extends as a series of straight thread-like processes between the rods, the amount of pigment between the rods being greater when the eye has been exposed to light. In the eyes of albinos the cells of the layer are destitute of pigment. The pigmented layer is more firmly attached to the choroid than to the retina proper,

so that in the clinical condition of 'detachment of the retina' the separation occurs, not between the retina and the choroid, but between the two layers of the retina, i.e. along the plane of the embryonic space between the layers of the optic cup.

FIG. 1020.—The macula lutea, the optic disc and the retinal blood-vessels of the left eye as seen on ophthalmoscopic examination.



Retina proper.*—The nervous structures of the retina proper are supported by a series of non-nervous, or sustentacular fibres, and, when examined microscopically by means of sections made perpendicular to the surface of the retina (figs. 1022 and 1023) are found to comprise seven layers, named from without inwards as follows:

1. Layer of rods and cones.
2. Outer nuclear layer.
3. Outer plexiform layer.
4. Inner nuclear layer.
5. Inner plexiform layer.
6. Ganglionic layer.
7. Stratum opticum.

The light reaches the stratum opticum first and, after traversing all the other layers, finally affects the rods and cones in the outermost layer. The nerve impulses which result from the stimulation of these photoreceptors then pass through the layers in the numerical order given above.

(1) *Layer of rods and cones.*—The elements of this layer are of two kinds, *rods* and *cones*, the former being more numerous than the latter except in the macula lutea. Over a diameter of 0.5 mm. in the fovea centralis rods are completely absent.

The rods and cones are the photoreceptors of the retina and each is part of a neurone, the other portions of which are contained in the outer nuclear and outer plexiform layers (fig. 1023).

The *rods* are cylindrical, of nearly uniform thickness, and are arranged perpendicularly to the surface of the retina. Each consists of two segments, an outer and an inner, of about equal lengths and differing one from another as regards refraction and in their behaviour towards colouring reagents. Visual purple is found in only the outer segments of the rods. The inner or deep ends rest against the membrana limitans externa and, through holes in the latter, are continuous with the other parts of the rod neurones in the outer nuclear layer.

The *cones* are conical, their broad ends resting on the membrana limitans externa, their pointed extremities facing towards the choroid. Each consists of two segments separated by a dividing zone showing a higher refraction. The outer segment is narrow and conical; the inner is rather wider and somewhat cylindrical in shape. The cones are usually slightly shorter than the rods of the same region and the inner segments are three to four times the thickness of the corresponding segments of the adjacent rods. Through holes in the membrana limitans externa pass constricted protoplasmic necks, which connect the inner segments of the cones proper with the other parts of the cone neurones in the outer nuclear layer.

(2) *The outer nuclear layer.*—This layer contains the cell-bodies of the rod and cone neurones, termed the rod-granules and the cone-granules. The *rod-granules* are placed at different levels throughout the layer. Each contains a nucleus, which almost completely fills it, and is connected by a peripheral process, termed the *outer rod-fibre*, with the inner segment of a rod. Each rod-granule also sends a central process, the *inner rod-fibre*, into the outer plexiform layer where it ends in a small, smooth, oval swelling termed the rod-spherule. The *cone-granules* are found in the part of the outer nuclear layer near the membrana limitans externa. Each contains a spherical nucleus and is continuous, by a constricted neck, with the inner segment of a cone. A thick central process is given off from each cone-granule and it passes into the outer plexiform layer where it expands into a pyramidal enlargement, the *cone foot-plate* or cone-pedicle, from which numerous fine fibrils originate.

* For a complete account of retinal structure, see *The Retina*, by S. L. Polyak. Univ. of Chicago Press, 1941.

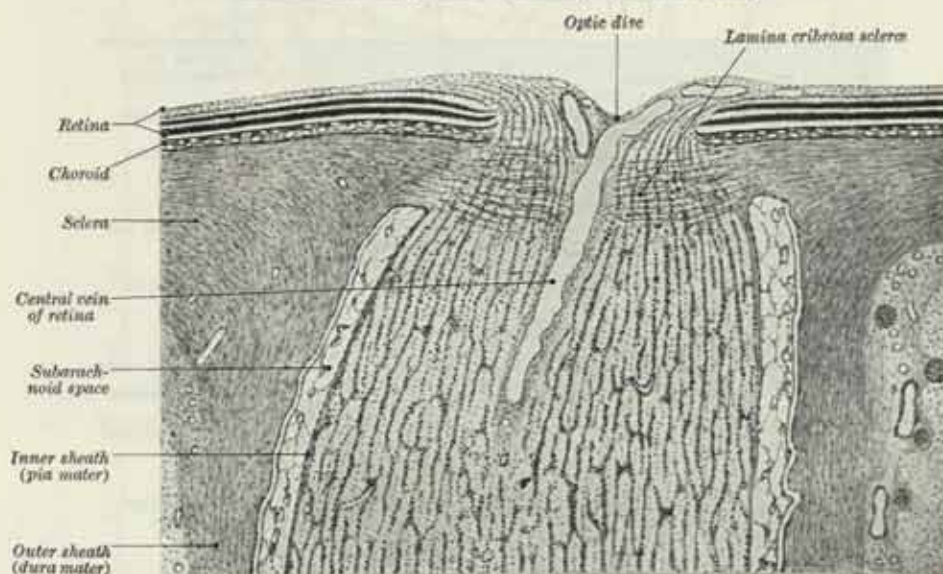
(3) *The outer plexiform layer.*—This is much the thinner of the two plexiform layers. It contains the rod-spherules and cone foot-plates and the peripheral processes of cells of the inner nuclear layer which are forming synapses with them.

(4) *The inner nuclear layer.*—This layer is made up of closely packed cells of which there are three varieties, viz.: bipolar cells, horizontal cells and amacrine cells.

The bipolar cells.—There are two main varieties of bipolar cells; one, the 'midget' bipolar cells, which form synapses in the outer plexiform layer with the foot-plates of individual cone-cells only, and the other bipolars which form synapses with both rod-spherules and cone foot-plates. In both cases the axons of the bipolar cells pass into the inner plexiform layer to form synapses with the dendrites of ganglion cells of layer 6. Some of the axons of the second variety of bipolar cells pass into layer 6 and form synapses with the cell bodies of the ganglion cells.

The horizontal cells.—These are found in the outer part of the inner nuclear layer. They probably connect cones of one part of the retina with rods and cones of adjacent parts.

FIG. 1021.—A horizontal section through the optic nerve at its point of entrance into the eyeball. (Human.) (After Sobotta.)



The amacrine cells.—These are found mainly in the inner part of the inner nuclear layer and were originally named 'amacrine' on the incorrect assumption that they had no axons. Some of the cells originally included in this group are probably neuroglial in character and belong to the supporting framework of the retina. Others, however, are true neurones, the function of which is uncertain. It is possible that some act as centrifugal bipolar neurones, connecting the ganglion cells of layer 6 and centrifugal fibres from the stratum opticum on the one hand, with the cone foot-plates on the other hand. Other amacrine cells possibly intercept impulses from bipolar neurones and spread them to nearby parts of the ganglion cell layer.

(5) *The inner plexiform layer.*—This contains the dendrites of the ganglion cells of layer 6 and the central processes of the bipolar cells which are forming synapses with them.

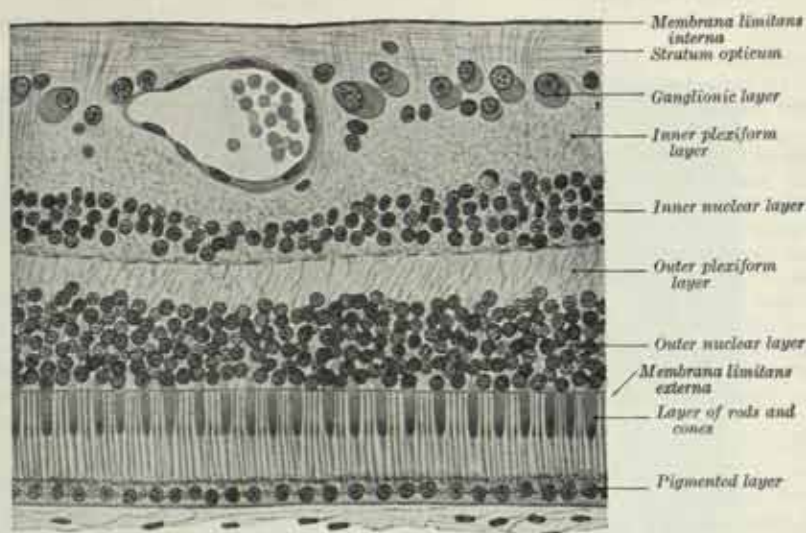
(6) *The ganglionic layer* consists of a single layer of large nerve-cells, except in the macula lutea, where there are several strata. The cells are somewhat flask-shaped, the rounded internal surface of each being in contact with, and sending an axon into, the stratum opticum. From the opposite end numerous dendrites extend into the inner plexiform layer, where they form flattened arborisations at different levels. The ganglion-cells vary much in size, and the dendrites of the smaller ones ('midget' ganglion cells) often arborise in the inner plexiform layer as soon as they enter it, and form synapses with the central processes of the 'midget' bipolars. The dendrites of the larger cells ramify close to the inner nuclear layer.

(7) *The stratum opticum or layer of nerve-fibres* is formed by the axons of the cells of the ganglionic layer; it is thickest near the optic disc, gradually thinning towards the ora serrata. The fibres form intercommunicating networks from which nerve

bundles converge towards the optic disc. The nerves are unmyelinated and, passing through the lamina cribrosa, they acquire myelin sheaths and constitute the fibres of the optic nerve. As in the case of the fibres in the central nervous system, these optic nerve-fibres are devoid of a neurolemma. A few fibres in the stratum opticum originate in the brain and end by ramifying around amacrine cells and among other elements of the inner nuclear layer of the retina. The retinal blood-vessels lie mainly in the stratum opticum (p. 1247).

Supporting framework of the retina.—The nervous layers of the retina are connected together by a supporting framework, formed by the *sustentacular fibres* (fig. 1023); these fibres pass through all the nervous layers, except that of the rods and cones. Each fibre begins on the inner surface of the retina by an expanded, often forked, base, which sometimes contains a spheroidal body, staining deeply with hæmatoxylin; the edges of the bases of adjoining fibres are united to form the *membrana limitans interna*. As the sustentacular fibres pass through the stratum opticum and the ganglionic layer they send off a few lateral branches; in the inner nuclear layer they give off numerous lateral processes for the support of the bipolar cells, while in the outer nuclear layer they form a network and unite to form the *membrana limitans externa* at

FIG. 1022.—A section through the retina (human). (After Sobotta.)



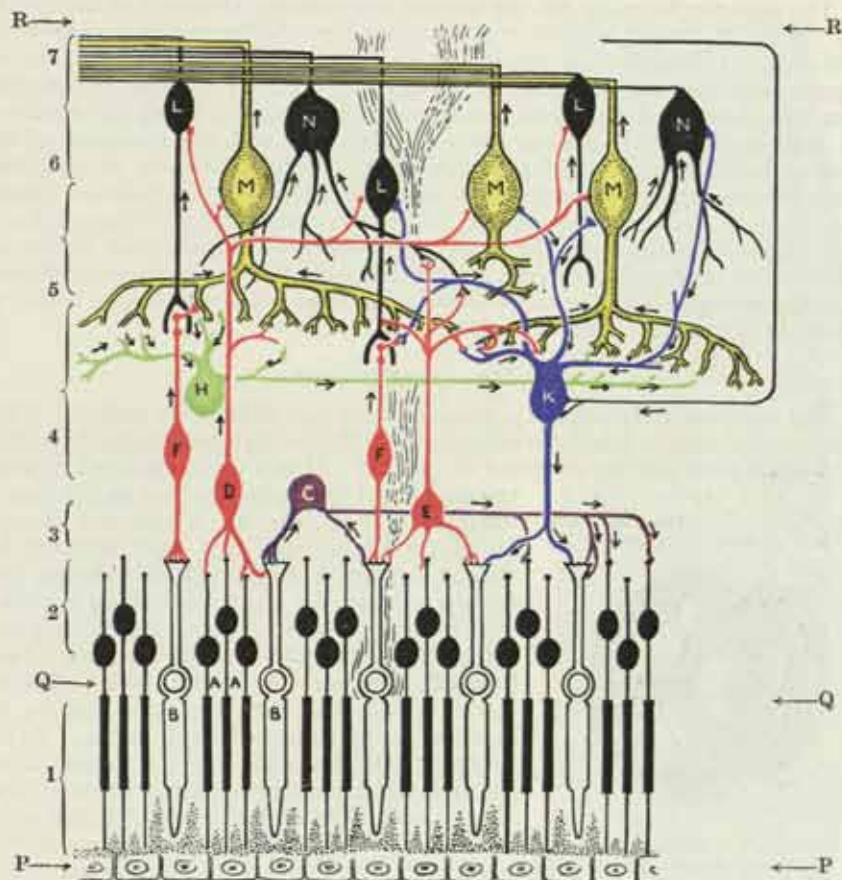
the bases of the rods and cones. At the level of the inner nuclear layer each sustentacular fibre contains a clear oval nucleus.

Structure of the macula lutea and fovea centralis.—At the fovea centralis there are no rods, and the cones are longer and thinner than in other parts of the retina. The nerve-fibre layer disappears at the margin of the fovea, and the other retinal layers are extremely thin. The pigment-cells are large and well marked. At the circumference of the fovea the retina rapidly increases in thickness, so that this part of the macula lutea has a greater depth than any other part of the retina. All the layers are involved in this increase, but especially the ganglionic layer, in which the cells are six to eight deep. The yellow colour of the macula seems to imbue all the layers except that of the rods and cones; it is deepest towards the centre of the macula, and does not appear to be due to pigment-cells, but simply to a staining of the constituent parts. The fovea, lying on the optic axis at the posterior pole of the eyeball, is the region of most acute vision. Here the retina consists almost solely of cones and contains no blood vessels, so that light impinges almost directly on the receptor elements (cones). Further, each cone is connected through one bipolar cell to one ganglion cell, resulting in greater acuity of vision. In more peripheral parts of the retina, a bipolar cell is connected to a number of rods and cones, so that (spatial) summation of subliminal light stimuli can occur, though this arrangement results in a lesser degree of acuity of vision.

At the *ora serrata* the nervous layers of the retina end abruptly, and the retina is continued onwards as a single layer of columnar cells along with the pigmented layer. This double layer is known as the *ciliary part of the retina*, and can be traced forwards from the ciliary processes on to the back of the iris, where it is termed the *iridial part of the retina*, in which both layers of cells are pigmented (p. 1243).

The *central artery of the retina* (fig. 1020) and its accompanying vein pierce the inferomedial surface of the optic nerve 1.25 cm. behind the eyeball, and enter the bulb of the eye at the centre of the optic disc. The artery immediately bifurcates into an upper and a lower branch, and each of these again divides into a nasal and a temporal

FIG. 1023.—A scheme of the retinal neurones. (Diagrammatic. Modified from Polyak.)



1. Layer of rods and cones. 2. Outer nuclear layer. 3. Outer plexiform layer. 4. Inner nuclear layer. 5. Inner plexiform layer. 6. Ganglionic layer. 7. Stratum opticum.
P. Pigmented layer. Q. Membrana limitans externa. R. Membrana limitans interna. One sustentacular fibre is indicated in the centre of the diagram. AA. Rods. BB. Cones. C. Horizontal cell. D and E. Bipolar cells forming synapses with rods and cones. FF. 'Midget' bipolar cells synapsing with cones only. HK. Amacrine cells. LL. Midget ganglion cells. MN. Other ganglion cells. Arrows indicate the probable direction of nerve-impulses.

branch, which at first run between the hyaloid membrane and the nervous layer ; but they soon enter the latter, and pass forwards, dividing dichotomously. From those branches a minute capillary plexus is given off, which does not extend beyond the inner nuclear layer. The layer of rods and cones and the outer nuclear layer are avascular and are nourished by diffusion from the choriocapillary lamina of the choroid (p. 1239). The macula receives two small branches (superior and inferior macular arteries) from the temporal branches, and small twigs directly from the central artery ; these do not, however, reach as far as the fovea centralis, which has no blood-vessels. The branches of the arteria centralis retinae do not anastomose with each other or with any other vessels—in other words, they are terminal arteries. In the fœtus, a small vessel, termed the hyaloid artery, passes forwards as a continuation of the central artery of the retina through the vitreous humour to the posterior surface of the capsule of the lens.

The retinal veins accompany the arteries and the central vein of the retina ends usually in the cavernous sinus, after giving off a branch to the superior ophthalmic vein ; sometimes it ends solely in the latter vein.

THE CONTENTS OF THE EYEBALL

The contents of the eyeball are the aqueous humour, the vitreous body and the lens. All play a part in refracting the rays entering the eye and the refracting power of the lens can be varied for near or far vision.

I. THE AQUEOUS HUMOUR

The **aqueous humour** fills the anterior and posterior chambers of the eyeball (fig. 1013). It is small in quantity and is formed as a dialysate from the capillaries of the ciliary processes, from which it passes into the posterior chamber. Thence it passes into the anterior chamber through the pupillary aperture and escapes from the iridocorneal angle into the anterior ciliary veins, through the spaces of the angle and the sinus venosus sclerae. Interference with the resorption of the aqueous humour into the sinus venosus sclerae results in increase of the intra-ocular tension—the condition known as glaucoma. The optic disc becomes cupped and, owing to degenerative changes in the nervous elements of the retina produced by pressure, blindness eventually results. The operation of iridectomy, performed in the earlier stages of the disease, re-establishes the flow of the aqueous humour from the posterior chamber to the anterior, in cases where the disease is due to adhesions between the iris and the lens.

II. THE VITREOUS BODY

The **vitreous body** (fig. 1013) occupies about four-fifths of the eyeball. It fills the concavity of the retina, and is hollowed in front, forming a deep concavity, termed the *hyaloid fossa*, for the reception of the lens. It is a colourless, structureless,

FIG. 1024.—The lens, hardened and divided. (Enlarged.)



transparent gel, consisting of about 99 per cent of water, with some salts and a little mucoprotein (vitrein) and hyaluronic acid. Only after fixation does it appear to have a fibrillar stroma (the *vitreous stroma*), the meshes of which are filled with a watery *vitreous humour*. At its periphery the gel is condensed to form the so-called *vitreous (hyaloid) membrane*. A narrow canal, called the *hyaloid canal*, runs from the optic disc to the centre of the posterior surface of the lens. In the fœtus the canal is occupied by the hyaloid artery (p. 148), which normally disappears before birth. The vitreous membrane is adherent to the retina

in two places, namely at the optic disc and immediately in front of the ora serrata. In the latter situation it is thickened by the accession of radial fibres and is termed the *ciliary zonule*. Here the membrane presents a series of radially arranged furrows, in which the ciliary processes are accommodated and to which they adhere, as is shown by the fact that when they are removed some of their pigment remains attached to the zonule. The ciliary zonule splits into two layers, one of which is thin and lines the hyaloid fossa of the vitreous body; the other, forming a system of *zonular fibres* which collectively comprises the *suspensory ligament of the lens*, is thicker and passes over the ciliary body to be attached to the capsule of the lens a short distance in front of its equator; some of the fibres of the suspensory ligament are attached behind the equator of the lens (fig. 1013). Scattered and delicate fibres are also attached to the region of the equator itself. This ligament retains the lens in position, and is relaxed by the contraction of the meridional fibres of the Ciliary muscle, so that the lens is allowed to become more convex (p. 1241). Encircling the equator of the lens, between the anterior and posterior fibres of the suspensory ligament, there is a series of sacculated spaces called the *zonular spaces*.

No blood-vessels penetrate the vitreous body; so that its nutrition must be carried on by the vessels of the retina and ciliary processes, situated upon its exterior.

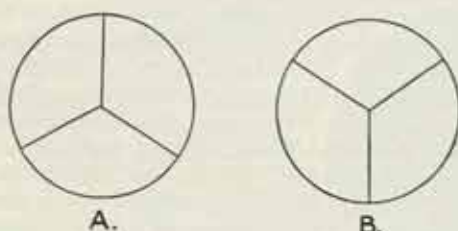
III. THE LENS

The **lens** (fig. 1013), enclosed in its capsule, is situated immediately behind the iris, in front of the vitreous body, and is encircled by the ciliary processes, which slightly overlap its margin.

The *capsule of the lens* is a transparent, structureless membrane which closely surrounds the lens, and is thicker in front than behind. It is brittle but highly elastic, and when it is ruptured the edges roll up with the outer surface innermost. The lens rests, behind, in the hyaloid fossa on the forepart of the vitreous body; in front, it is in contact with the free border of the iris, but recedes from

FIG. 1027.—A section through the margin of the lens, showing the transition of the columnar epithelium into the lens-fibres. (Babuchin.)

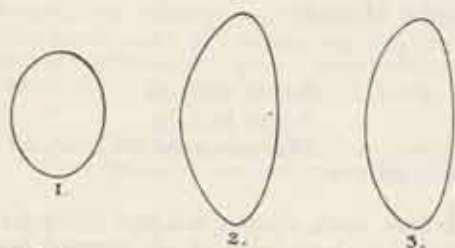
FIG. 1025.—A diagram showing the direction and arrangement of the radiating lines on the foetal lens. A. On the back. B. On the front.



it at the circumference, thus forming the posterior chamber of the eye; it is retained in its position chiefly by the suspensory ligament already described.

The *lens* is a transparent, biconvex body, the convexity of its anterior being less than that of its posterior surface. The central points of these surfaces are termed respectively the *anterior* and *posterior poles*; a line connecting the poles constitutes the *axis* of the lens, while the marginal circumference is termed the *equator*.

FIG. 1026.—Profile views of the lens at different periods of life.



1. In the fetus. 2. In adult life. 3. In old age.

Structure.—The lens is made up of soft cortical substance and a firm, central part, the so-called nucleus (fig. 1024). Faint sutural lines [radii lentis] radiate from the poles to the equator. In the adult there may be six or more of these lines, but in the fetus there are only three, and these diverge in a Y-shaped manner at angles of 120° ; on the anterior surface the Y is upright (fig. 1025, B); on the posterior surface the Y is inverted (fig. 1025, A).^{*} These lines correspond with the free edges of septa composed of an amorphous substance, which dip into the substance of the lens. When the lens has been hardened it is seen to consist of a series of concentrically arranged laminae, each of which is interrupted at the septa. Each lamina is built up of a number of ribbon-like lens-fibres, the edges of which

^{*} Consult an article on "The Anatomy of the Living Eye as Revealed by the Gullstrand Slit-lamp," by Ida C. Mann (*J. Anat.*, 59, 1924).

are more or less serrated—the serrations fitting between those of neighbouring fibres, while the ends of the fibres come into apposition at the septa. The fibres run in a curved manner from the septa on the anterior surface to those on the posterior surface. No fibres pass from pole to pole; they are arranged in such a way that those which begin near the pole on one surface of the lens end near the peripheral extremity on the other, and vice versa. The fibres of the outer layers of the lens are nucleated, and together form a nuclear layer, most distinct towards the equator. The anterior surface of the lens is covered by a layer of transparent, nucleated columnar epithelium. At the equator the cells become elongated, and their gradual transition into lens-fibres can be traced (fig. 1027).

In the fœtus, the lens is nearly spherical and has a slightly reddish tint; it is soft and breaks down readily on the slightest pressure. A small branch (hyaloid artery) from the central artery of the retina runs forwards through the vitreous body to the posterior part of the capsule of the lens, where its branches radiate, forming a plexiform network which covers the posterior surface of the capsule, and is continuous round the margin of the capsule with the vessels of the pupillary membrane and with those of the iris. *In the adult*, the lens is colourless, transparent, firm in texture and devoid of vessels. *In old age*, it becomes flattened on both surfaces (fig. 1026), slightly opaque, of an amber tint and increased in density. In the condition termed cataract the lens gradually becomes opaque and blindness ensues. In such cases sight may be restored by extraction of the lens and the provision of suitable glasses.

Vessels and Nerves.—The arteries of the eyeball are the long, short, and anterior ciliary arteries, and the central artery of the retina. They have already been described (pp. 1242 and 1247).

The ciliary veins are seen on the outer surface of the choroid, and are named, from their arrangement, the *venæ vorticosæ*; they converge to four or five equidistant trunks, which pierce the sclera midway between the sclerocorneal junction and the optic disc. Another set of veins accompanies the anterior ciliary arteries. All these veins open into the ophthalmic veins.

The ciliary nerves are derived from the nasociliary nerve and from the ciliary ganglion.

THE ACCESSORY ORGANS OF THE EYE

The accessory organs of the eye include the orbital muscles, the fasciæ, the eyebrows, the eyelids, the conjunctiva and the lacrimal apparatus.

THE ORBITAL MUSCLES

The orbital muscles are the:

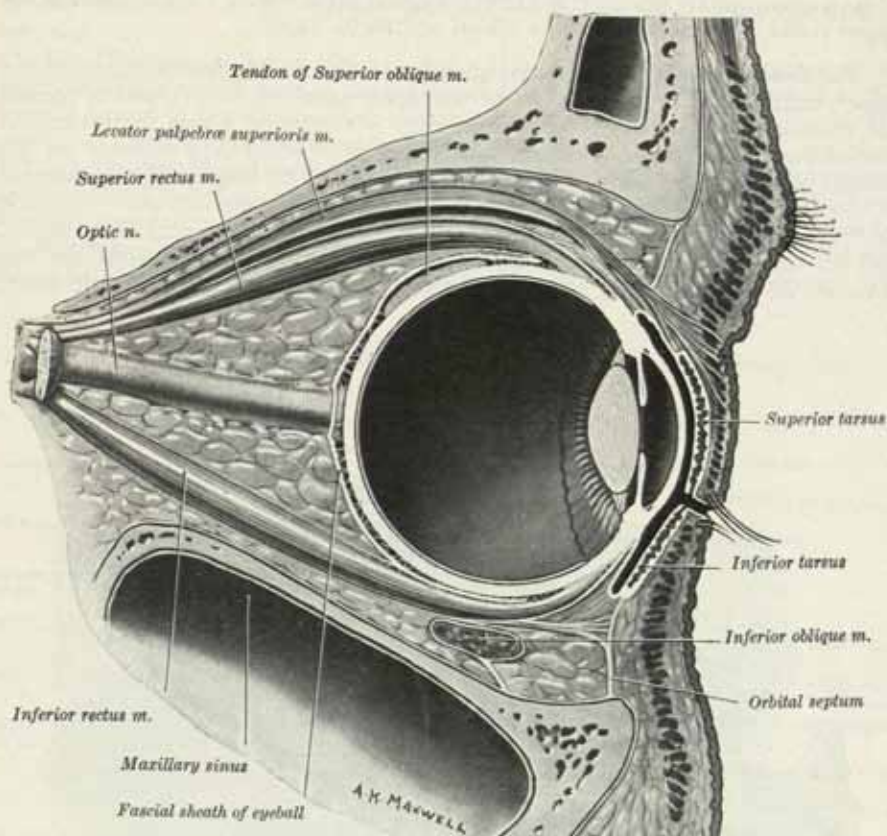
Levator palpebræ superioris.	Rectus medialis.
Rectus superior.	Rectus lateralis.
Rectus inferior.	Obliquus superior.
Obliquus inferior.	

The **Levator palpebræ superioris** (figs. 1028, 1029) is thin and triangular in shape. It arises from the under surface of the lesser wing of the sphenoid bone, above and in front of the optic canal, from which it is separated by the origin of the Rectus superior. At its origin, it is narrow and tendinous but soon becomes broad and fleshy, the medial margin of the muscle being almost straight, while the lateral margin is concave. The muscle ends anteriorly in a wide aponeurosis which splits into two lamellæ. Some of the fibres of the superficial lamella are attached to the anterior surface of the superior tarsus (p. 1258), while others radiate and pass through the overlying Orbicularis oculi to the skin of the upper eyelid. The deep lamella consists of non-striped muscular fibres; * it is attached directly to the upper margin of the superior tarsus and is covered by conjunctiva on its inferior surface.

The fascial sheaths of the Levator palpebræ superioris and Rectus superior fuse. Where the two muscles separate to reach their insertions, the fascia between them forms a thick mass which is fixed to the superior conjunctival fornix and is described as an additional insertion of the Levator palpebræ superioris. When traced laterally

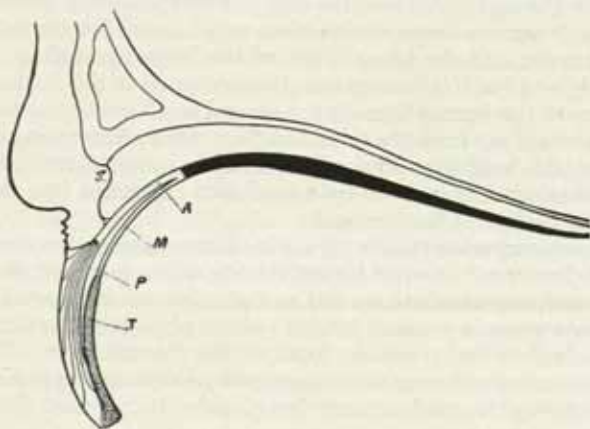
* A less well marked layer of non-striped muscle is also present in the lower eyelid; it unites the inferior tarsus to the fascial sheath of the Inferior rectus and its expansion to the sheath of the Inferior oblique.

FIG. 1028.—A sagittal section through the right orbital cavity.



the aponeurosis of the Levator palpebrae superioris passes between the orbital and palpebral parts of the lacrimal gland and is fixed to a tubercle on the zygomatic bone, just within the orbital margin (p. 352). When traced medially the aponeurosis loses its tendinous nature as it passes over and comes into close contact with the reflected tendon of the Obliquus superior, whence it can be followed with difficulty towards the medial palpebral ligament in the form of loose strands of connective tissue. When the

FIG. 1029.—A diagram of the Levator palpebrae superioris, showing its connexions. (From Whitnall's *Anatomy of the Human Orbit*, Oxford Medical Publications.)

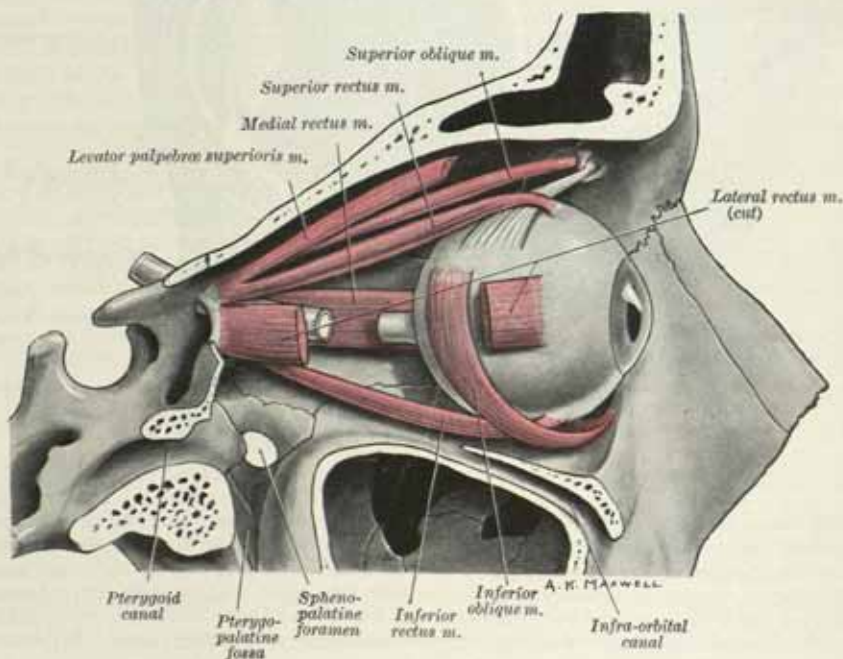


A, Superficial lamella of aponeurosis; M, Deep lamella (Müller's muscle); P, Interval between superficial and deep lamellae of aponeurosis; T, Tarsus; S, Orbital septum.

Levator palpebræ contracts, the upper eyelid is raised, but the lateral and medial parts of the aponeurosis are stretched and limit the action of the muscle ; the elevation of the upper eyelid is checked also by the orbital septum (p. 1259).

The **four Recti** (figs. 1030, 1031) arise from a fibrous ring which surrounds the upper, medial, and lower margins of the optic canal (fig. 1032), and is termed the *common tendinous ring*; the fibrous ring is continued across the lower and medial part of the superior orbital fissure and is attached to a tubercle on the margin of the greater wing of the sphenoid bone. The ring is closely adherent to the sheath of the optic nerve and to the surrounding periosteum; within it are (1) the optic canal transmitting the optic nerve and ophthalmic artery, and (2) the medial part of the superior orbital fissure which transmits the two divisions of the oculomotor nerve, the nasociliary nerve, and the abducent nerve.

FIG. 1030.—The muscles of the right orbit. Lateral aspect.



The superior ophthalmic vein may pass through, or above, the ring; the inferior ophthalmic vein through, or below, the ring. Two specialised parts of this fibrous ring may be made out: a lower, which gives origin to the Rectus inferior, a part of the Rectus medialis, and the lower fibres of the Rectus lateralis; and an upper, which gives origin to the Rectus superior, the other part of the Rectus medialis, and the upper fibres of the Rectus lateralis; a second small tendinous head of origin of the Rectus lateralis arises from the orbital surface of the greater wing of the sphenoid bone, lateral to the tendinous ring. Each muscle passes forward in the position implied by its name, to be inserted by a tendinous expansion into the sclera, about 6 mm. from the margin of the cornea.*

The **Obliquus superior** (fig. 1030) is a fusiform muscle, placed at the upper and medial side of the orbit. It arises from the body of the sphenoid above and medial to the optic canal, superior and medial to the origin of the Rectus superior, and, passing forwards, ends in a round tendon, which plays in a fibrocartilaginous ring or pulley attached to the trochlear fossa of the frontal bone. The contiguous surfaces of the tendon and ring are lubricated by a delicate synovial sheath. After traversing the pulley the tendon passes backwards, laterally and downwards below

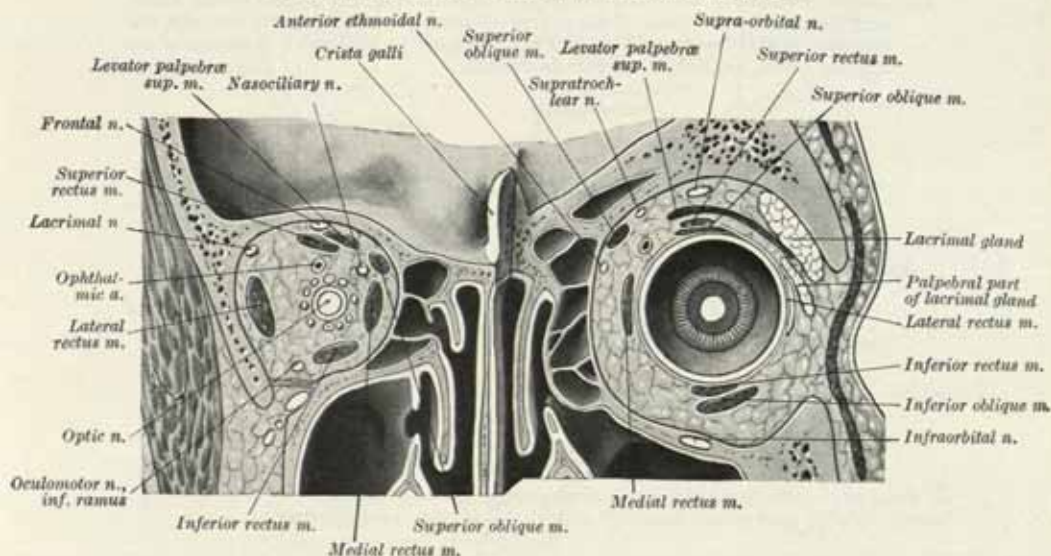
* The average distances of the insertions of the Recti from the margin of the cornea are: Rectus medialis, 5.5 mm.; Rectus inferior, 6.5 mm.; Rectus lateralis, 6.9 mm.; Rectus superior, 7.7 mm.

the Rectus superior, to the lateral part of the eyeball, and is inserted into the sclera, behind the equator of the eyeball, and between the Rectus superior and Rectus lateralis.

The **Obliquus inferior** (fig. 1030) is a thin, narrow muscle, placed near the anterior margin of the floor of the orbit. It arises from the orbital surface of the maxilla lateral to the nasolacrimal groove. Passing laterally, backwards and upwards, at first between the Rectus inferior and the floor of the orbit, and then between the eyeball and the Rectus lateralis, it is inserted into the lateral part of the sclera, behind the equator of the eyeball, between the Rectus superior and Rectus lateralis, near to, but somewhat behind, the insertion of the Superior oblique muscle.

Nerves.—The Levator palpebræ superioris, the Obliquus inferior, and the Recti superior, inferior et medialis are supplied by the oculomotor nerve; the

FIG. 1031.—Coronal sections through the two orbits. On the left side the plane of the section is more posterior and passes behind the eyeball.



Obliquus superior, by the trochlear nerve; the Rectus lateralis, by the abducent nerve.

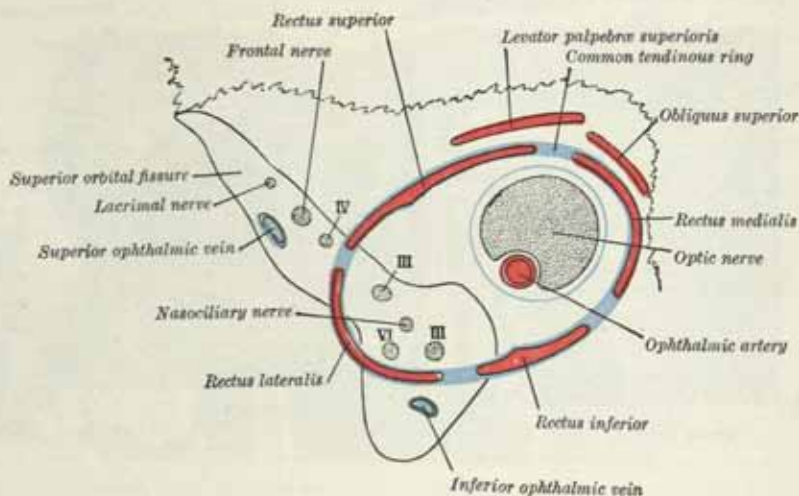
Actions.—The Levator palpebræ raises the upper eyelid, and is the direct antagonist of the Orbicularis oculi. The four Recti are attached to the eyeball in such a manner that, acting singly, they will turn its corneal surface either upwards, downwards, medially, or laterally, as expressed by their names. The movements produced by the Rectus superior and by the Rectus inferior are not simple, for inasmuch as each passes obliquely laterally and forwards to the eyeball, the elevation or depression of the cornea is accompanied by a certain deviation medially, with a slight amount of rotation. These latter movements are corrected by the Oblique muscles. The Obliquus inferior rotates the eyeball so as to turn its corneal surface upwards and laterally. When the eye is directed upwards, the Inferior oblique corrects the medial deviation caused by the Rectus superior. The Obliquus superior rotates the eyeball so as to turn its corneal surface downwards and laterally. When the eye is directed downwards, the Superior oblique corrects the medial deviation caused by the Rectus inferior. The contraction of the Rectus lateralis or Rectus medialis, on the other hand, produces a purely horizontal movement. If any two neighbouring Recti of one eye act together they carry the globe of the eye in the diagonal of these directions, viz. upwards and medially, upwards and laterally, downwards and medially, or downwards and laterally. Sometimes the corresponding Recti of the two eyes act in unison, and at other times the opposite Recti act together. Thus, in turning the eyes to the right (conjugate deviation), the Rectus lateralis of the right eye acts in unison with the Rectus

medialis of the left eye; but if both eyes are directed to an object in the median plane at a short distance (convergence), the two medial Rectus muscles act in unison. The movement of circumduction, as in looking round a room, is performed by the successive actions of the four Recti. The Oblique muscles rotate the eyeball on its transverse and vertical axes, the superior directing the cornea downwards and laterally, and the inferior directing it upwards and laterally; these movements are required for the correct viewing of an object when the head is moved laterally, as from shoulder to shoulder, in order that the picture may fall in all respects on the same part of the retina of either eye.

A thin layer of non-stripped muscle, named the *Orbitalis muscle*, bridges the inferior orbital fissure.

The **fascial sheath of the eyeball** (figs. 1033, 1034) is a thin membrane which envelops the eyeball from the optic nerve to the sclerocorneal junction, separating it from the orbital fat and forming a socket in which it plays. Its inner surface is

FIG. 1032.—Scheme to show the common tendinous ring, the origins of the Recti, and the relative positions of the nerves entering the orbital cavity through the superior orbital fissure. (Modified from a figure in Whitnall's *Anatomy of the Human Orbit*, Oxford Medical Publications.)



N.B.—The ophthalmic veins frequently pass through the common tendinous ring.

smooth, and is separated from the outer surface of the sclera by the *episcleral space*; this space is traversed by delicate bands of connective tissue which extend between the fascia and the sclera. The fascia is perforated behind by the ciliary vessels and nerves, and fuses with the sheath of the optic nerve and with the sclera around the entrance of the optic nerve. In front it blends with the sclera just behind the sclerocorneal junction. It is perforated by the tendons of the orbital muscles, and is reflected on each as a tubular sheath. The sheath of the Superior oblique is carried as far as the fibrous pulley of that muscle; that on the Inferior oblique reaches as far as the floor of the orbit, to which it gives off a slip. The sheaths on the Recti are gradually lost in the perimysium, but they give off important expansions. The expansion from the Rectus superior blends with the tendon of the Levator palpebrae superioris; that of the Rectus inferior is attached to the inferior tarsus and to the sheath of the Inferior oblique. The expansions from the sheaths of the Recti medialis et lateralis are strong and triangular in shape, and are attached to the lacrimal and zygomatic bones respectively; as they probably check the actions of these two Recti they have been named the *medial* and *lateral check ligaments*. Lockwood* described a thickening of the lower part of the fascial sheath of the eyeball, which he named the *suspensory ligament of the eye*; it is slung like a hammock below the eyeball, being expanded in the centre and narrow at its extremities; it is formed by the union of the margins of the sheath of the Rectus inferior with the

* C. B. Lockwood, *J. Anat. Physiol.*, 1886, 20, 1.

FIG. 1033.—A scheme of the fascia of the orbit (the muscle-sheaths and the fascial sheath of the eyeball) in sagittal section. (From Whitnall's *Anatomy of the Human Orbit*; Oxford Medical Publications.)

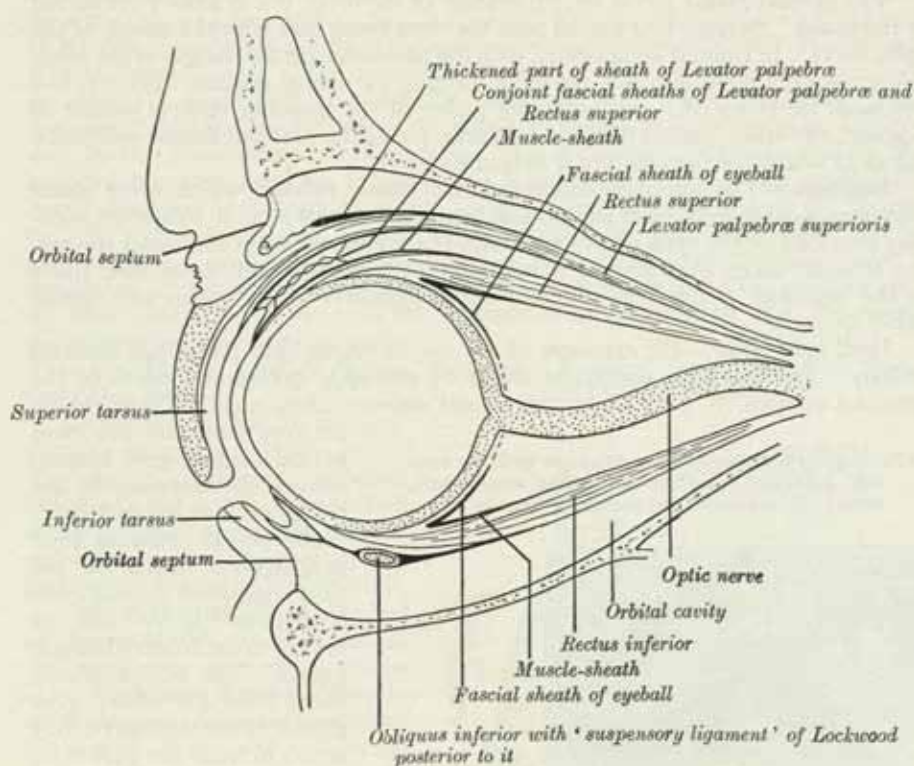
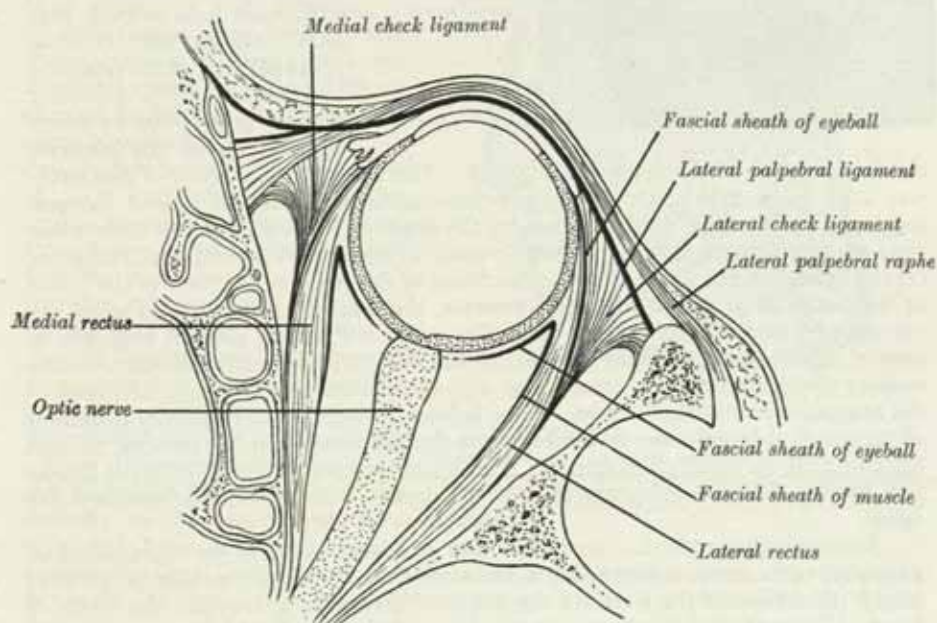


FIG. 1034.—A schematic view of a horizontal section through the right orbit to illustrate the fascia of the orbit. (From Whitnall's *Anatomy of the Human Orbit*; Oxford Medical Publications.)



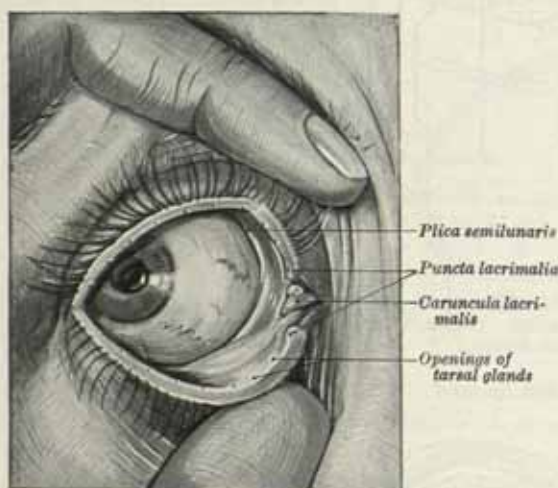
medial and lateral check ligaments. Nutt * has emphasized that anomalies of the various parts of the above fascial arrangements may interfere with the normal movements of the eyes and cause various types of squint.

The **orbital fascia** forms the periosteum of the orbit, but is loosely connected to the bones. Behind, it is united with the dura mater and with the sheath of the optic nerve. In front, it is connected with the periosteum at the margin of the orbit, and sends off a stratum which assists in forming the orbital septum. From it two processes are given off: one holds the pulley of the Superior oblique muscle in position, the other, named the *lacrimal fascia*, forms the roof and lateral wall of the sulcus in which the lacrimal sac is lodged (p. 1261).

Reflexes.—The impulses concerned with *visual reflexes*, which bring about movements of the eyes, head and neck in response to visual stimuli, follow the pathway provided by the optic nerves and tracts to the superior colliculi. After traversing synapses there, the impulses travel along the tectospinal and tectobulbar tracts to the neurones of the final common motor pathways of the spinal and cranial nerve (p. 997).

Pupil light reflex.—On exposure of the eye to bright light the pupils contract reflexly. The impulses concerned travel by the optic nerves and tracts to the pretectal nucleus (p. 997) where the second neurone fibres arise. These, which

FIG. 1035.—The front of the right eye with the eyelids separated to show the plica semilunaris, caruncula lacrimalis and puncta lacrimalia.



are very short and run close to the central grey matter, convey the impulses to the Edinger-Westphal nucleus (p. 1096), whose neurones send preganglionic fibres to the ciliary ganglion through the oculomotor nerve and its branch to the Inferior oblique muscle. The postganglionic fibres from the ciliary ganglion traverse the short ciliary nerves to reach the Sphincter pupillæ. If light be shone into one eye only, both pupils contract (consensual pupil light reflex); this is due to the fact that fibres from one optic tract pass to both pretectal nuclei, the crossing fibres passing via the posterior commissure. The Dilator pupillæ is supplied by fibres which arise in the superior

cervical ganglion of the sympathetic trunk. The preganglionic fibres of this pathway arise from cells of the lateral grey column in the first and second thoracic segments of the spinal cord and pass by the upper thoracic nerves and their white rami communicantes to the sympathetic trunk in which they ascend to the superior cervical ganglion (p. 1211). As the condition of the pupil at any time is the result of the balanced action of these two systems, the pupil becomes dilated when the stimulus of bright light is removed. The pupil will dilate, also, in response to painful stimulation of almost any part of the body. Presumably the fibres of the sensory pathways establish connexions with the efferent preganglionic neurones of the sympathetic described above. Some believe, however, that this reflex dilatation of the pupil is largely due to inhibition of the Edinger-Westphal nucleus, though the pathways involved are uncertain. One manifestation of this reflex is the dilatation produced by pinching the skin of the neck; it is termed the *pupillary-skin reflex*.

Accommodation reflexes.—In the process of accommodation for the viewing of near objects the eyes converge and, at the same time, the Ciliary muscle contracts to modify the shape of the lens and the pupil is constricted to increase the depth of focus. The pathways for the accommodation reflex comprise the optic nerve, optic

* A. B. Nutt, *Annals Roy. Coll. Surg. Eng.*, 1955, 16, 30.

tract, lateral geniculate body, optic radiation and the visual area of the cerebral cortex. The latter is connected by the superior longitudinal association tract to the eye field of the frontal cortex, whence fibres descend through the internal capsule to the nuclei of the oculomotor nerves in the midbrain. From the Edinger-Westphal nuclei fibres pass to the Ciliary and Sphincter pupillæ muscles (relaying in the ciliary ganglion) and from the central nucleus fibres supply the Medial recti muscles for the action of convergence of the eyes. These pathways have not been so definitely established as those for the pupil light reflex, and it has been suggested* that the contraction of the pupil in the accommodation reflex is secondary to the convergence of the eyes and that the afferent impulses arise in the proprioceptor nerve endings in the ocular muscles and travel in the oculomotor nerve direct to the Edinger-Westphal nuclei. In certain diseases of the central nervous system (e.g. tabes dorsalis due to syphilis) the pupil light reflex may be lost whilst the constriction of the pupil as part of the accommodation reflex is unaffected (Argyll-Robertson pupil). The site of the lesion that could produce such an effect probably lies between the Edinger-Westphal nucleus and the lateral geniculate body, where the pathways for the two reflexes diverge from each other.

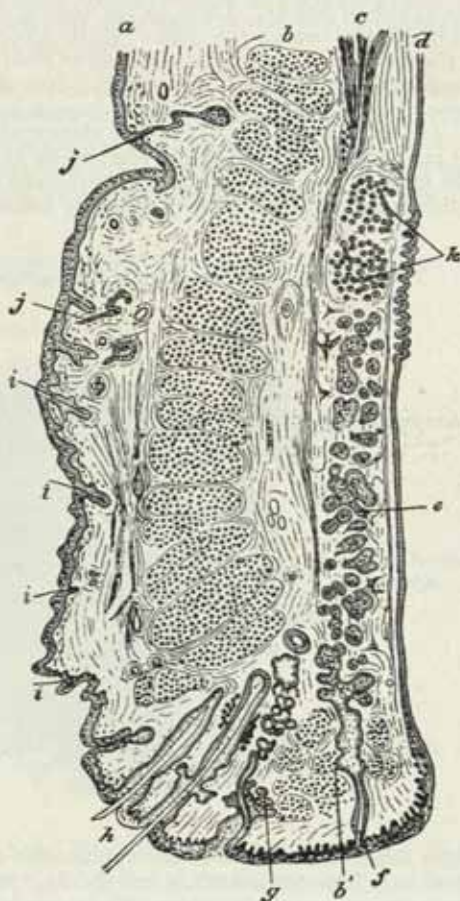
Conjunctival reflex. If the conjunctiva be touched lightly, blinking occurs. Afferent impulses travel via the ophthalmic part of the trigeminal nerve and efferent impulses in the branches of the facial nerve to the Orbicularis oculi.

The **eyebrows** are two arched eminences of skin, which surmount the orbits and support numerous short, thick hairs directed obliquely on the surface. Fibres of the Orbicularis oculi, Corrugator and frontal belly of the Occipito-frontalis are inserted into the skin of the eyebrows.

The **eyelids** or **palpebræ** are two thin, movable folds, placed in front of the eye, and protecting it, by their closure, from injury. The upper eyelid is the larger and more movable, and is furnished with an elevator muscle [the Levator palpebræ superioris] (p. 1250); the two eyelids unite with each other at their extremities. When the eyelids are open, an elliptical space, termed the *palpebral fissure*, is left between their margins; the extremities of the fissure are called the angles of the eye.

The *lateral angle of the eye* is more acute than the medial, and lies in close contact with the eyeball. The *medial angle* is prolonged for a short distance towards the nose, and is about 6 mm. away from the eyeball; the two eyelids are here separated by a triangular space, named the *lacus lacrimalis*, in which a small reddish body, termed the *caruncula lacrimalis*, is situated (fig. 1035). On the margin of each eyelid, at the basal angles

FIG. 1036.—A sagittal section through the upper eyelid. (After Waldeyer.)



a. Skin. b. Orbicularis oculi. b'. Ciliary bundle of the Orbicularis oculi. c. Levator palpebræ superioris. d. Conjunctiva. e. Tarsal glands embedded in the tarsal plate. f. Opening of a tarsal gland. g. Sebaceous gland. h. Eyelashes. i. Small hairs of the skin. j. Sweat gland. k. Posterior tarsal glands.

* Wilkinson, H. J., "Argyll-Robertson Pupil," *Med. Journal of Australia*, 1927, vol. i, pp. 267-272.

of the lacus lacrimalis, there is a small conical elevation, termed the *lacrimal papilla*, the apex of which is pierced by the commencement of the lacrimal canaliculus. This minute orifice (fig. 1035) is known as the *punctum lacrimale*.

The *eyelashes* are attached to the free edges of the eyelids from the lateral angle of the eye to the lacrimal papillæ. They are short, thick, curved hairs, arranged in double or triple rows: those of the upper eyelid, more numerous and longer than those of the lower, curve upwards; those of the lower eyelid curve downwards so that the upper and lower eyelashes do not interlace when the lids are closed. A number of enlarged and modified sudoriferous glands, termed *ciliary glands*, are arranged in several rows close to the free margin of each lid and open near the attachments of the eyelashes.

Structure of the eyelids.—From without inwards, each eyelid consists of: skin, subcutaneous areolar tissue, fibres of the *Orbicularis oculi*, tarsus and orbital septum, tarsal glands and conjunctiva. The upper eyelid has, in addition, the aponeurosis of the *Levator palpebræ superioris* (fig. 1036).

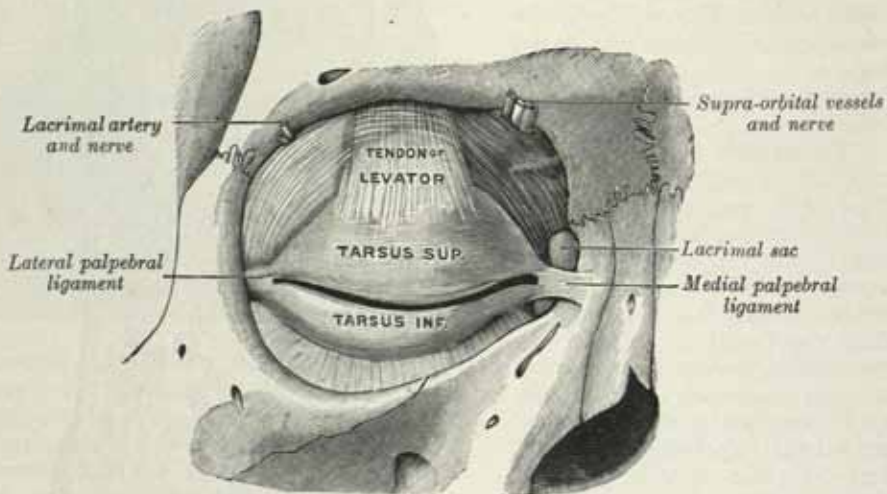
The *skin* is extremely thin, and continuous at the margins of the eyelids with the conjunctiva.

The *subcutaneous areolar tissue* is very lax and delicate, and seldom contains any fat.

The *palpebral fibres of the Orbicularis oculi* are thin, pale in colour and parallel with the palpebral fissure. Deep to the muscle there is a layer of loose areolar tissue, which, in the case of the upper eyelid, is continuous with the subaponeurotic layer of the scalp (p. 553), so that effusions of fluid (blood or pus) in this layer of the scalp can pass down into the upper eyelid. It is in this layer of the eyelids that the main nerves lie, so that local anaesthetics have to be injected deep to the *Orbicularis oculi*.

The *tarsi* (fig. 1037) are two thin elongated plates of dense connective tissue, about 2.5 cm. long; one is placed in each eyelid and contributes to its form and support. The *tarsus of the upper eyelid*, the larger, is of a semi-oval form, about 10 mm. in height at the centre, and gradually narrowing towards its extremities. The lowest fibres

FIG. 1037.—The tarsi and their ligaments. Anterior aspect. (Testut.)



of the superficial lamella of the aponeurosis of the *Levator palpebræ superioris* are attached to its anterior surface, and the deep lamella of the same aponeurosis is inserted into its upper margin (p. 1250). The *tarsus of the lower eyelid*, the smaller, is a narrow plate, the vertical diameter of which is about 5 mm. The free or ciliary margins of the tarsi are thick and straight. The attached or orbital margins are connected to the circumference of the orbit by the orbital septum. The lateral ends of the tarsi are attached by a band, named the *lateral palpebral ligament*, to a tubercle on the zygomatic bone, just within the orbital margin; this ligament is separated from the more superficially placed lateral palpebral raphe (p. 555) by a few lobules of the lacrimal gland. The medial ends of the tarsi are attached by a strong tendinous band, named the *medial palpebral ligament*, to the upper part of the lacrimal crest, and to the adjoining part of the frontal process of the maxilla in front of this crest; the lower edge of this ligament is separated from the lacrimal sac by some fibres of the *Orbicularis oculi*.

The *orbital septum* is a weak membranous sheet, attached to the edge of the orbit, where it is continuous with the periosteum. In the upper eyelid it blends with the superficial lamella of the aponeurosis of the *Levator palpebræ superioris*, and in the lower eyelid with the anterior surface of the tarsus. It is perforated by the vessels and nerves which pass from the orbital cavity to the face and scalp, by the aponeurosis of the *Levator palpebræ superioris*, and by the palpebral part of the lacrimal gland.

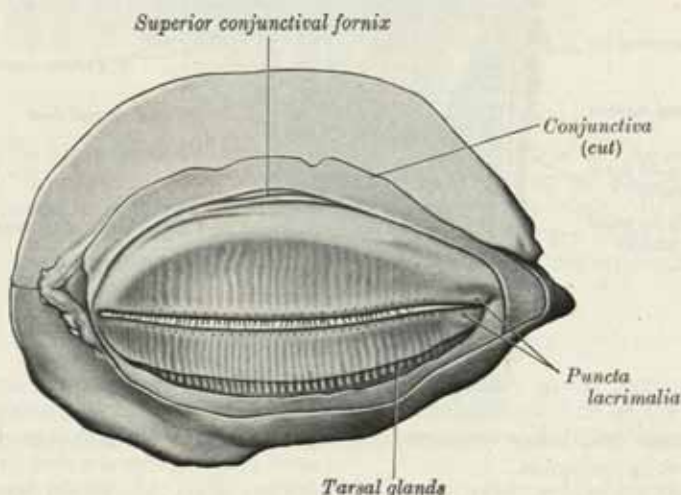
The *tarsal glands* (fig. 1038) are situated between the tarsi and the conjunctiva, and may be distinctly seen through the latter on everting the eyelids; they present an appearance like parallel strings of pearls. They are yellow in colour, arranged in a single row, and number about thirty in the upper eyelid, and somewhat fewer in the lower. They are imbedded in grooves on the deep surfaces of the tarsi and correspond in length with the breadth of these plates; they are, consequently, longer in the upper than in the lower eyelid. Their ducts open on the free margins of the lids by minute foramina.

Structure.—The tarsal glands are modified sebaceous glands, each consisting of a straight tube or follicle, with numerous small lateral diverticula. The tubes are supported by a basement-membrane and are lined at their mouths by stratified epithelium; the deeper parts of the tubes and the lateral off-shoots are lined by a layer of polyhedral cells. The secretion of the glands spreads over the margin of the eyelid and tends to prevent the tears from overflowing on to the cheek.

The *conjunctiva* is the transparent mucous membrane which lines the inner surfaces of the eyelids, and is reflected over the fore part of the sclera and the cornea.

The *palpebral portion* is highly vascular, and has numerous subepithelial connective tissue papillæ, its deeper part containing a considerable amount of lymphoid tissue, especially near the fornices. It is intimately adherent to the tarsi. At the

FIG. 1038.—The deep surfaces of the upper and lower eyelids of the left side. The orifices of the tarsal glands can be seen on the free margins of the lids.

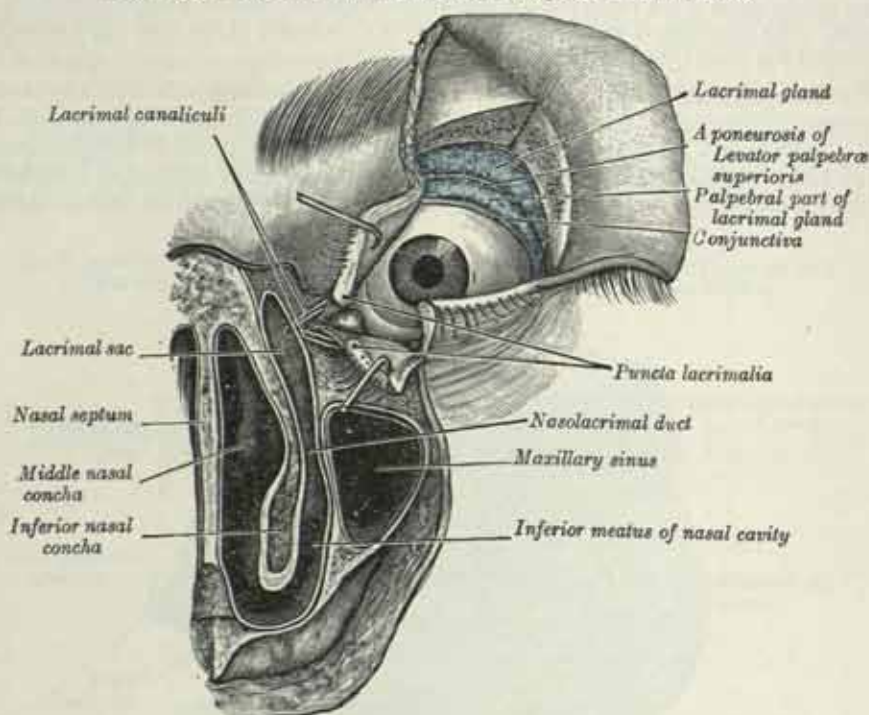


margins of the lids it is continuous with the skin, with the lining epithelium of the ducts of the tarsal glands, and, through the lacrimal canaliculi, with the lining membrane of the lacrimal sac and nasolacrimal duct. The line of reflection of the conjunctiva from the eyelids on to the eyeball is named the *conjunctival fornix*, and its different parts are known as the superior and inferior fornices; the ducts of the lacrimal gland open into the lateral part of the superior fornix. Upon the *sclera* the conjunctiva is loosely connected to the eyeball; it is thin, transparent, destitute of papillæ, and only slightly vascular. Upon the *cornea*, the conjunctiva consists only of epithelium, constituting the epithelium of the cornea, already described (p. 1238). The epithelium of the palpebral conjunctiva near the margins of the eyelids is stratified squamous like the epidermis; about 2 mm. from the edge of each eyelid there is a groove in which foreign bodies frequently lodge and at which

the epithelium comes to consist of two layers, a superficial one of columnar cells and a deeper one of flattened cells. This structure persists throughout most of the palpebral conjunctiva, but as the fornices are approached an intermediate layer of polygonal cells appears and this trilaminar arrangement comprises the structure of the conjunctival epithelium over the sclera. Near the sclerocorneal junction the epithelium changes to the stratified type characteristic of the corneal epithelium (p. 1238). Scattered throughout the conjunctival epithelium there are mucus-secreting goblet cells.

The *lacrimal caruncle* (fig. 1035) is a small, reddish, conical body situated in the lacus lacrimalis at the medial angle of the eye; it consists of a small island of skin, and contains sebaceous and sudoriferous glands; a few slender hairs are attached to its surface. Lateral to, and partly under cover of, the caruncula there is a semilunar fold of conjunctiva, the *plica semilunaris*, the concave free lateral edge of which is directed towards the cornea. Its epithelium resembles that of the conjunctiva on the sclera but it contains numerous goblet cells. Beneath the epithelium there is some fat and a little unstriped muscle. Some consider the caruncle to represent the nictitating membrane (or third eyelid) found in many

FIG. 1039.—The left lacrimal apparatus. Exposed from the front.



mammals and lower vertebrates, though Stibbe * maintains that these structures are not homologous.

Vessels and Nerves.—The eyelids receive their blood-supply from the medial palpebral branches of the ophthalmic artery and from the lateral palpebral branches of the lacrimal artery (p. 757).

The ocular conjunctiva is supplied by the ophthalmic division of the trigeminal nerve. The conjunctiva of the upper eyelid is supplied by the ophthalmic nerve, that of the lower eyelid by the maxillary nerve. Many of the nerves to the conjunctiva end in bulbous corpuscles (p. 920).

The lymph vessels of the eyelids and the conjunctiva are described on p. 887.

Movements of the eyelids.—The position of the lids at any particular time depends on the reciprocal tone of the Orbicularis oculi and Levator palpebræ superioris muscles, and on the degree of protrusion of the eyeball. The usual position when the eyes are open is that the margin of the lower lid crosses the eyeball at the lower edge of the circumference of the iris whilst the upper lid covers about half the width

* E. P. Stibbe, *Trans. Ophthal. Soc., U.K., 1927, 47.*

of the uppermost portion of the iris. The eyes are closed by movement of both upper and lower lids produced by contraction of the *Orbicularis oculi* muscle and at the same time the *Levator palpebrae superioris* relaxes. On looking upwards, the *Levator palpebrae superioris* contracts and the upper lid follows the movement of the eyeball. At the same time the eyebrows are raised by the contraction of the frontal bellies of the *Occipito-frontalis* so as to diminish the degree to which the eyebrows jut beyond the eye. The lower lid lags behind the movement of the eye so that much more of the sclera is exposed below the iris and the lid is bulged forwards to some extent by the pressure exerted against its deep surface by the lower part of the eyeball. On looking downwards both lids move, the upper retaining its normal

FIG. 1040.—A section through a part of the lacrimal gland, showing the acini lined by a layer of columnar cells and a few myo-epithelial cells can be seen outside the basement membrane. $\times 320$.



relationship to the eyeball and still covering about half the width of the upper portion of the iris. The lower lid is probably dragged downwards by the pull exerted on it by the conjunctiva reflected on to its deep surface from the sclera. In conditions of fear the palpebral fissure is widened by the contraction of the fibres of plain muscle in the *Levator palpebrae superioris* in response to the greater activity of the sympathetic nervous system.

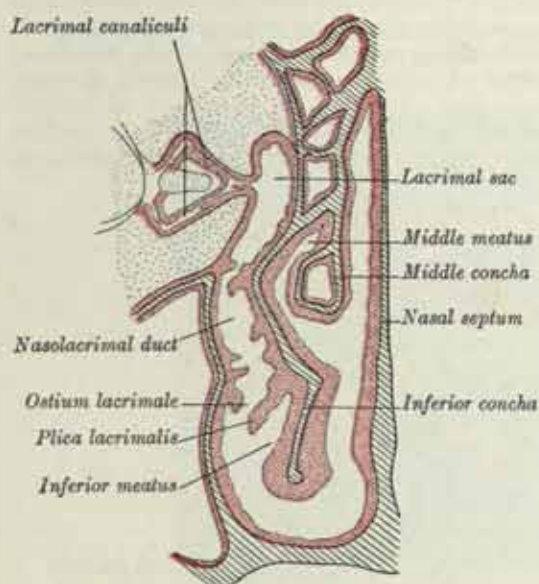
THE LACRIMAL APPARATUS (figs. 1039 to 1042)

The lacrimal apparatus consists of (a) the lacrimal gland, which secretes the tears, and its excretory ducts which convey the fluid to the surface of the eye; (b) the lacrimal canaliculi, the lacrimal sac, and the nasolacrimal duct, by which the fluid is conveyed into the cavity of the nose.

The **lacrimal gland** (fig. 1039) consists of a larger upper *orbital part* and a lower smaller *palpebral part*, the two parts being continuous with each other posterolaterally around the lateral concave edge of the aponeurosis of the *Levator palpebrae superioris*. The orbital part is about the size and shape of an almond and is lodged in the lacrimal fossa on the medial side of the zygomatic process of the frontal bone, just within the margin of the orbit. It lies above the *Levator* (and, further laterally, above the *Lateral rectus*); its lower surface is connected to the sheath of the *Levator*, its upper surface is connected to the orbital periosteum, its anterior border is in contact with the orbital septum and its posterior border is attached to the orbital fat. The palpebral part, which is about one-third of the size of the orbital part, is subdivided into two or three lobules and extends below the aponeurosis of the *Levator* into the lateral part of the upper eyelid, where it is attached to the superior fornix of the conjunctiva through which it can be seen when the eyelid is everted. The ducts of the gland, about 12 in number,

open into the superior conjunctival fornix. Those from the orbital part (4 or 5 in number) pass through the palpebral part and are joined by some of the ducts from this latter part, while other ducts of the palpebral part (6 to 8 in number) open independently. Thus all the ducts pass through the palpebral part, so that excision of this part of the gland is functionally equivalent to removal of the entire gland.

FIG. 1041.—Sketch from a coronal section through the right half of the nasal cavity, viewed from the front, to show the relation of the lacrimal passages to the maxillary and ethmoidal sinuses and the inferior nasal concha. The mucous membrane is coloured. (After Gerard, 1907; from Whitnall's *Anatomy of the Human Orbit*; Oxford Medical Publications.)



Many small accessory lacrimal glands are present in and near the conjunctival fornices; they are more numerous in the upper lid than in the lower. Their existence may explain why the conjunctiva does not dry up after extirpation of the lacrimal gland proper.

Structure of the lacrimal gland (fig. 1040).—The gland consists of very small lobules and is a compound tubulo-alveolar gland. The acini are lined by a layer of columnar cells which rest on a basement membrane and contain secretion granules and fat droplets. Outside these there are flattened myo-epithelial (contractile) cells. The ducts are lined by a layer of columnar cells, outside which are a few myo-epithelial cells. The secretion of the gland (tears) contain various salts and an enzyme (lysozyme) which is bacteriocidal.

Nerves.—The nerve supply of the lacrimal gland is described on p. 1115.

The **lacrimal canaliculi**, one in each eyelid, are about 10 mm. long; they commence at the *puncta lacrimalia* (figs. 1035, 1039, 1041). The *superior canaliculus*, smaller and shorter than the inferior, at first ascends, and then bends at an acute angle, and passes medially and downwards to the lacrimal sac. The *inferior canaliculus* at first descends, and then runs almost horizontally to the lacrimal sac. At the angles they are dilated into *ampullae*. The mucous lining of the ducts is covered with stratified squamous epithelium, placed on a basement-membrane, and outside the latter there is a corium rich in elastic fibres (rendering the ducts easily dilatable during the passage of a probe) and a layer of striped muscular fibres, continuous with the lacrimal part of the *Orbicularis oculi*; at the base of each lacrimal papilla the muscular fibres are circularly arranged and form a kind of sphincter.

The **lacrimal sac** (figs. 1037, 1039, 1041) is the upper blind end of the nasolacrimal duct, and is lodged in a fossa formed by the lacrimal bone, the frontal process of the maxilla and the lacrimal fascia. It measures about 12 mm. in length; its upper, closed end is flattened from side to side, but its lower part is rounded, and is continued into the nasolacrimal duct; the openings of the lacrimal canaliculi are situated in its lateral wall slightly below its upper end.

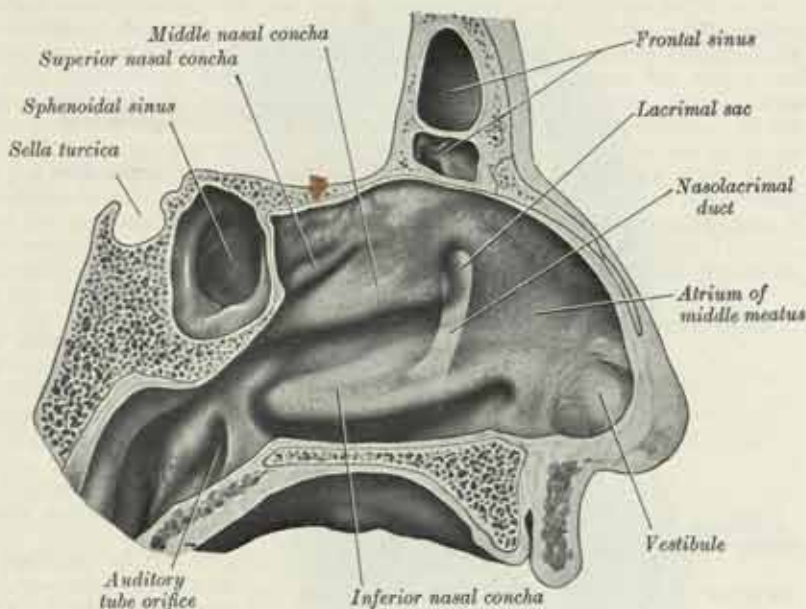
Relations.—A layer of fascia, continuous with the periosteum of the orbit and named the *lacrimal fascia*, passes from the lacrimal crest of the maxilla to the crest of the lacrimal bone, and forms the roof and lateral wall of the fossa in which the lacrimal sac is lodged; between the fascia and the lacrimal sac there is a plexus of minute veins. The lacrimal fascia separates the sac from the medial palpebral ligament in front, and from the lacrimal part of the *Orbicularis oculi* behind. The lower half of the fossa which lodges the lacrimal sac is related

medially to the anterior part of the middle meatus of the nasal cavity; the upper half is related to the anterior ethmoidal cellules.*

Structure.—The lacrimal sac consists of a fibro-elastic coat, lined internally by mucous membrane; the latter is continuous, through the lacrimal canaliculi, with the conjunctiva, and through the nasolacrimal duct with the mucous membrane of the nasal cavity.

The **nasolacrimal duct** (figs. 1041, 1042) is a membranous canal about 18 mm. long, which extends from the lower part of the lacrimal sac to the anterior part of the

FIG. 1042.—The left lateral wall of the nose viewed from the medial side. The lacrimal sac and the nasolacrimal duct of the left side have been projected on to the lateral wall of the nose to show their positions relative to the middle nasal concha, the middle meatus and the inferior nasal concha. $\times \frac{1}{2}$. (After Whitnall.)



inferior meatus of the nose, where it ends in a somewhat expanded orifice. A fold of the mucous membrane forms an imperfect valve just above the opening and is known as the *lacrimal fold*. The duct is contained in an osseous canal, formed by the maxilla, the lacrimal bone and the inferior nasal concha; it is narrower in the middle than at either end, and is directed downwards, backwards and a little laterally. The mucous lining of the lacrimal sac and nasolacrimal duct is covered with two layers of columnar epithelium which in places is ciliated. Around the duct there is a rich plexus of veins, forming an erectile tissue, engorgement of which may obstruct the duct.

The tears secreted by the lacrimal gland enter the conjunctival sac at its supero-lateral angle and, under the influence of capillarity aided by blinking movements of the eyelids, are carried across the sac to the lacus lacrimalis mainly along the groove between the lower lid margin and the eyeball. From the lacus they pass into the lacrimal canaliculi. Contraction of the *Orbicularis oculi* tends to turn the puncta lacrimalia inwards and capillary attraction serves to suck the lacrimal secretion into the lacrimal sac. The sudden dilatation of the lacrimal sac produced by the lacrimal part of the *Orbicularis oculi* during blinking movements (p. 556) probably assists the process. Under normal conditions the secretion of the tarsal glands prevents the

* S. E. Whitnall (*Ophthalmic Review*, Nov. 1911) examined 100 skulls and found that in 14 the anterior ethmoidal cellules came into relation only with the posterior wall of the fossa; in 32 they reached as far forward as the suture between the lacrimal bone and the maxilla; while in 54 one large irregular cellule extended forward as far as the anterior lacrimal crest.

tears from overflowing the lid margins and also covers the capillary film of fluid on the front of the eyeball with a film of oil which delays evaporation.*

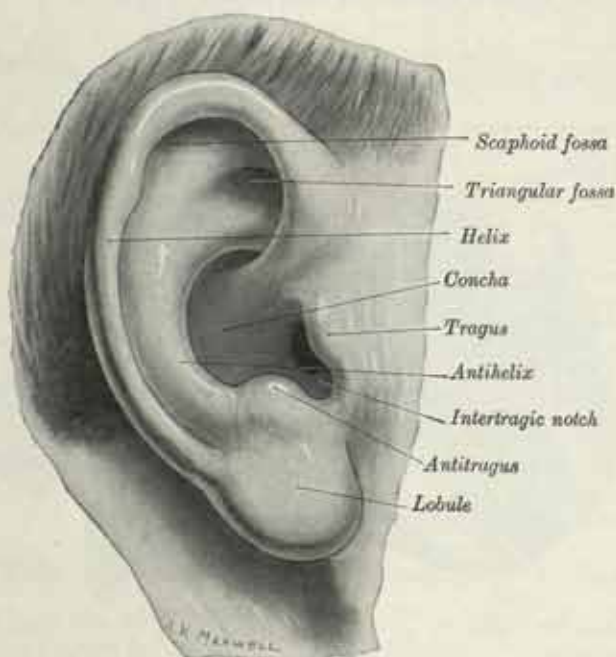
THE ORGAN OF HEARING

The ear or organ of hearing is divisible into three parts: the external ear, the middle ear or tympanic cavity, and the internal ear or labyrinth.

THE EXTERNAL EAR

The **external ear** consists of the expanded portion named the *auricle* and the *external acoustic meatus*. The former projects from the side of the head and serves

FIG. 1043.—The right auricle. Lateral surface.



to collect the air-vibrations by which sound is produced; the meatus leads inwards from the bottom of the auricle and conducts the vibrations to the tympanic membrane.

The **auricle** (fig. 1043) is of an oval form, with its larger end directed upwards. Its lateral surface is irregularly concave, looks slightly forwards, and presents numerous eminences and depressions. The prominent rim of the auricle is called the *helix*; where the helix turns downwards posteriorly, a small tubercle termed the *auricular tubercle*, is frequently seen; this tubercle is very evident about the sixth month of intrauterine life, when the whole auricle has a close resemblance to that of some of the adult monkeys. Another curved prominence, parallel with and in front of the posterior part of the helix, is called the *antihelix*; this divides above into two crura, between which is a depression, named the *triangular fossa*. The narrow curved depression between the helix and the antihelix is called the *scaphoid fossa*; the antihelix partly encircles a deep, capacious cavity, named the *concha of the auricle*, which is incompletely divided into two parts by the *crus* or anterior end of the helix. The part of the concha above the crus of the helix is called the *cymba conchæ*; it overlies, and through it can be felt, the suprameatal triangle (pp. 278, 1274), deep to which lies the tympanic antrum. Below the crus of the helix and in front of the concha, a small, curved flap, termed the *tragus*, projects backwards over the orifice of the meatus. Opposite the tragus, and separated from it by the

* Wolff, E., "Anatomy of the Eye and Orbit." Third edn. H. K. Lewis, 1948.

intertragic notch, there is a small tubercle, named the *antitragus*. The *lobule* lies below the antitragus. Being composed of fibrous and adipose tissues the lobule is soft, unlike the rest of the auricle which is firm and elastic.

The cranial surface of the auricle presents elevations which correspond to the depressions on its lateral surface, and after which they are named, e.g. *eminentia conchæ*, *eminentia fossæ triangularis*, etc.

Structure.—The auricle is composed of a thin plate of elastic fibrocartilage, covered with skin, and connected with the surrounding parts by ligaments and muscles; it is continuous with the cartilaginous portion of the external acoustic meatus, and the latter is joined to the margins of the bony meatus by fibrous tissue.

The *skin of the auricle* is thin, closely adherent to the cartilage, and covered with fine hairs which are furnished with sebaceous glands; these glands are most numerous in the concha and scaphoid fossa. On the tragus and antitragus, and in the intertragic notch the hairs are strong and numerous, especially in the male in old age. The skin of the auricle is continuous with that lining the external acoustic meatus.

The *cartilage of the auricle* (fig. 1044) is formed of elastic fibrocartilage and consists of a single piece; upon its surface the eminences and depressions above described are found. It is absent from the lobule; it is deficient, also, between the tragus and beginning of the helix, the gap being filled up by dense fibrous tissue. At the front part of the auricle, where the helix bends upwards, there is a small projection of the cartilage, called the *spine of the helix*, while at the other extremity of the helix the cartilage is prolonged downwards as a tail-like process, named the *tail of the helix*; the latter is separated from the antihelix by the *fissura antitragohelicina*. The cranial surface of the cartilage shows the *eminentia conchæ* and the *eminentia triangularis* in positions corresponding to the depressions on the lateral surface. A transverse furrow, named the *sulcus antihelicis transversus*, which corresponds with the inferior crus of the antihelix on the lateral surface, separates the *eminentia conchæ* from the *eminentia triangularis*. The *eminentia conchæ* is crossed by a vertical ridge (*ponticulus*) which gives attachment to the *Auricularis posterior* muscle. In the cartilage of the auricle there are two fissures, one behind the crus helicis and another in the tragus.

The *ligaments of the auricle* consist of two sets: (1) extrinsic, connecting it to the temporal bone; (2) intrinsic, connecting various parts of its cartilage together.

The *extrinsic ligaments* are two in number, anterior and posterior. The *anterior ligament* extends from the tragus and spine of the helix to the root of the zygomatic process of the temporal bone. The *posterior ligament* passes from the posterior surface of the concha to the lateral surface of the mastoid process.

The chief *intrinsic ligaments* are: (a) a strong fibrous band, stretching from the tragus to the helix, completing the meatus in front, and forming part of the boundary of the concha; and (b) a band between the antihelix and the tail of the helix. Other less important bands are found on the cranial surface of the auricle.

The *muscles of the auricle* consist of two sets: (1) the extrinsic, which connect it with the skull and scalp and move the auricle as a whole; and (2) the intrinsic, which extend from one part of the auricle to another.

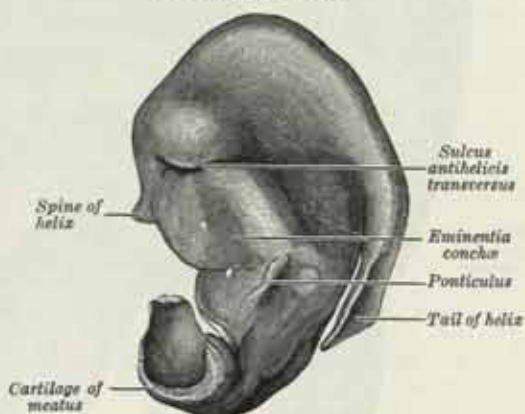
The *extrinsic muscles* are the *Auriculares anterior, superior et posterior*.

The *Auricularis anterior*, the smallest of the three, is thin, fan-shaped, and its fibres are pale and indistinct. It arises from the lateral edge of the epicranial aponeurosis, and its fibres converge to be inserted into the spine of the helix.

The *Auricularis superior*, the largest of the three, is thin and fan-shaped. Its fibres arise from the epicranial aponeurosis, and converge to be inserted by a thin, flattened tendon into the upper part of the cranial surface of the auricle.

The *Auricularis posterior* consists of two or three fleshy fasciculi, which arise by short aponeurotic fibres from the mastoid portion of the temporal bone, and are inserted into the ponticulus on the *eminentia conchæ*.

FIG. 1044.—The cranial surface of the cartilage of the right auricle.



Nerve-supply.—The Auriculares anterior et superior are supplied by the temporal branches, and the Auricularis posterior by the posterior auricular branch, of the facial nerve.

Actions.—In man, these muscles have very little action; the Auricularis anterior draws the auricle forwards and upwards; the Auricularis superior raises it slightly; and the Auricularis posterior draws it backwards.

The **intrinsic muscles** are the :

Helicis major.
Helicis minor.
Tragicus.

Antitragicus.
Transversus auriculæ.
Obliquus auriculæ.

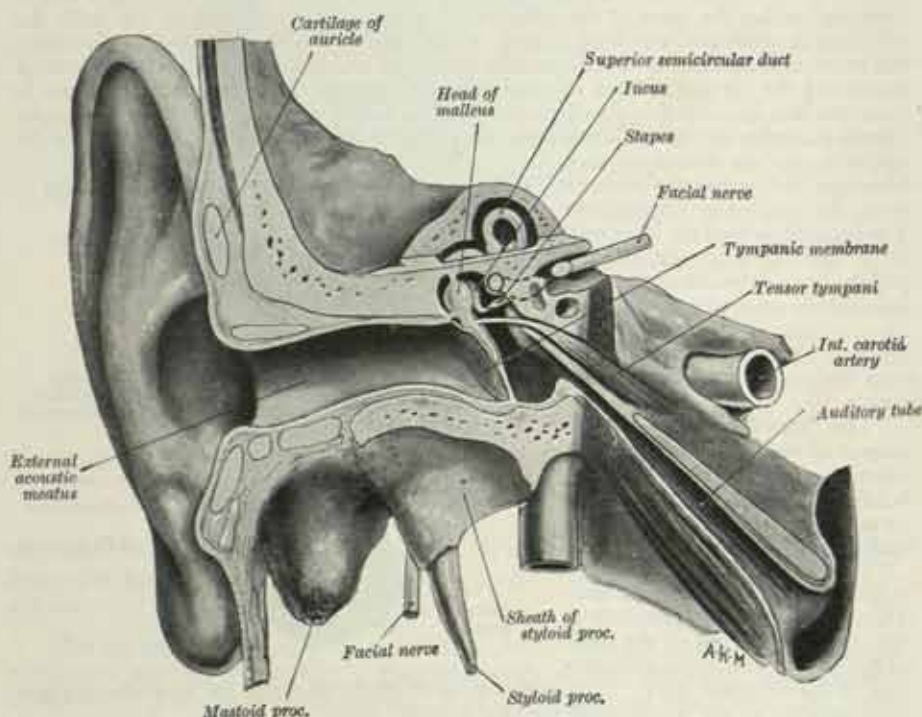
The *Helicis major* is a narrow vertical band situated upon the anterior margin of the helix. It arises from the spine of the helix, and is inserted into the anterior border of the helix, where the latter is about to curve backwards.

The *Helicis minor* is an oblique fasciculus, covering the crus helicis.

The *Tragicus* is a short, flattened vertical band on the lateral surface of the tragus.

The *Antitragicus* arises from the outer part of the antitragus, and is inserted into the tail of the helix and antihelix.

FIG. 1045.—The external and middle portions of the right ear, from the front.



The *Transversus auriculæ* is placed on the cranial surface of the auricle. It consists of scattered fibres, partly tendinous and partly muscular, extending from the eminentia conchæ to the eminentia scaphæ.

The *Obliquus auriculæ*, also on the cranial surface, consists of a few fibres extending from the upper and posterior parts of the eminentia conchæ to the eminentia triangularis.

Nerve-supply.—The intrinsic muscles on the lateral surface are supplied by the temporal branches of the facial nerve, the intrinsic muscles on the cranial surface by the posterior auricular branch of the same nerve.

The **arteries of the auricle** are : (a) the posterior auricular branch of the external carotid artery, which supplies three or four branches to the cranial surface; twigs from these reach the lateral surface, some by passing through the fissures of the auricular cartilage, and others by turning round the margin of the helix; (b) the anterior auricular branches of the superficial temporal artery, which are distributed to the lateral surface; and (c) a branch from the occipital artery.

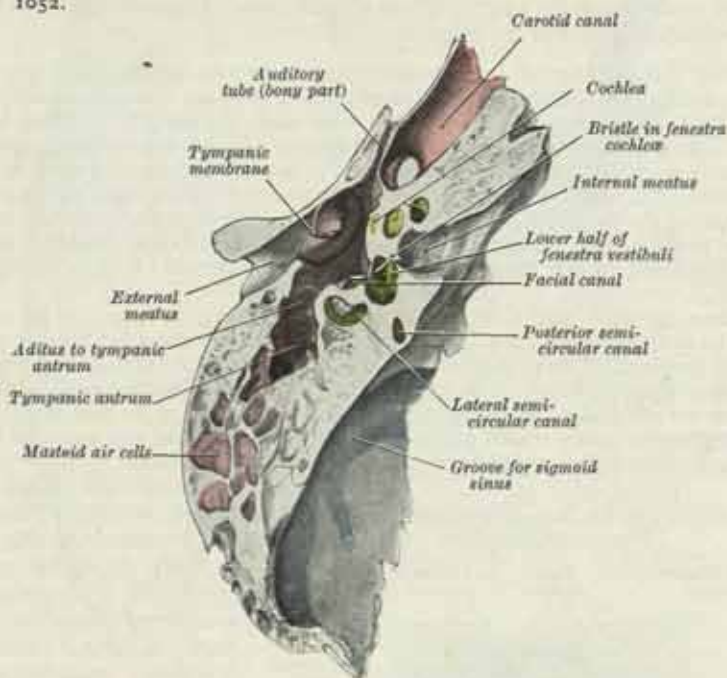
The *veins* accompany the corresponding arteries. Arteriovenous anastomoses (p. 700) are numerous in the skin of the auricle.

The *lymphatics* drain into (a) the parotid lymph nodes, especially the node in front of the tragus; (b) the upper deep cervical lymph nodes; and (c) the mastoid lymph nodes.

The *sensory nerves* (fig. 962) are: (a) The great auricular nerve which supplies most of the cranial surface and the posterior part of the lateral surface (helix, antihelix, lobule); (b) the lesser occipital nerve which supplies the upper part of the cranial surface; (c) the auricular branch of the vagus which supplies the concavity of the concha and the posterior part of the eminentia conchæ; (d) the auriculo-temporal nerve which supplies the tragus, the crus of the helix and the adjacent part of the helix; and (e) the facial nerve which supplies a small area over the eminentia conchæ, this cutaneous distribution of the facial nerve being evidenced by the distribution of vesicles in cases of herpes affecting the facial ganglion.

The **external acoustic meatus** (figs. 1045, 1946) extends from the concha to the tympanic membrane. Its length, measured from the bottom of the concha, is 2.5 cm. (measured from the tragus it is about 4 cm. long). It consists of two parts; the lateral third is called the *cartilaginous portion* and the medial two-thirds the

FIG. 1046.—An oblique section through the left temporal bone viewed from above. (From a section prepared by Mr. P. F. Milling.) Compare with figs. 1048 and 1052.



osseous portion. It forms an S-shaped curve, and is directed at first medially, forwards, and slightly upwards (*pars externa*); it then passes medially, backwards, and upwards (*pars media*), and lastly is carried medially, forwards, and slightly downwards (*pars interna*). It is a canal, oval on section, the greatest diameter of the oval being directed downwards and backwards at the external orifice, but nearly horizontally at the medial end. It presents two constrictions, one near the medial end of the cartilaginous portion, and another, named the *isthmus*, in the osseous portion, about 2 cm. from the bottom of the concha. The tympanic membrane, which closes the medial end of the meatus, is obliquely directed; in consequence of this obliquity, the floor and anterior wall of the meatus are longer than the roof and posterior wall.

The *cartilaginous portion* is about 8 mm. long; it is continuous with the cartilage of the auricle and is fixed to the circumference of the osseous portion. The cartilage is deficient at the upper and posterior parts of the meatus, its place being supplied by fibrous membrane; two or three deep fissures are present in the anterior part of

the cartilage through which an abscess in the parotid gland may burst into the meatus.

The *osseous portion* is about 16 mm. long, and is narrower than the cartilaginous portion. It is directed medially, forwards, and slightly downwards, forming in its course a slight curve the convexity of which is upwards and backwards. Its medial end is smaller than the lateral end, and is sloped, the anterior wall projecting beyond the posterior for about 4 mm.; this end is marked, except at its upper part, by a narrow groove, named the *tympanic sulcus*, in which the circumference of the tympanic membrane is attached. Its lateral end is dilated, and rough in the greater part of its circumference for the attachment of the cartilaginous portion. The anterior, inferior and most of the posterior parts of the osseous portion are formed by the tympanic part of the temporal bone, which, in the fœtus, exists as the tympanic ring (p. 327). The posterosuperior part of the osseous portion is formed by the squamous part of the temporal bone.

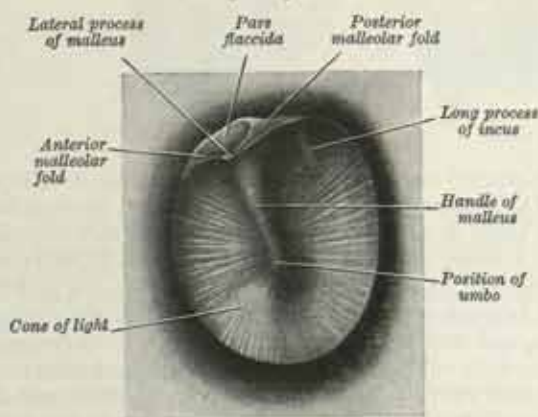
The skin which envelops the auricle is continued into the external acoustic meatus and covers the outer surface of the tympanic membrane. It is thin and closely adherent to the cartilaginous and osseous parts of the tube; hence inflammatory conditions are extremely painful owing to the increased tension in these tissues. In the thick subcutaneous tissue of the cartilaginous part of the meatus there are numerous *ceruminous glands*, which secrete the ear-wax; their structure resembles that of the sweat glands (p. 1302). These glands, as well as hair follicles, are limited to the cartilaginous part of the meatus.

Relations of the meatus.—The condyloid process of the mandible lies in front of the meatus, partially separated from the cartilaginous part by a small portion of the parotid gland. A blow or fall on the chin may cause the condyle to break into the meatus. The movements of the mandible influence to some extent the lumen of the cartilaginous portion. Above the osseous part is the middle cranial fossa; behind it are the mastoid air-cells, separated from the meatus by a thin layer of bone. The deepest part of the meatus is related superiorly to the epitympanic recess and posterosuperiorly to the tympanic antrum, the bone separating the antrum being only 1–2 mm. thick at this place, so that the antrum can be opened surgically by this 'transmeatal approach'.

The *arteries* supplying the meatus are the posterior auricular branch of the external carotid, the deep auricular branch of the maxillary and the auricular branches of the superficial temporal. The *veins* drain into the external jugular and maxillary veins and the pterygoid venous plexus. The *lymphatics* drain with those of the auricle (p. 1267).

The *nerves* are derived from the auriculotemporal branch of the mandibular nerve which supplies the anterior and upper walls of the meatus, and the auricular branch of the vagus nerve which supplies the posterior and inferior walls.

FIG. 1047.—The left tympanic membrane, seen as through a speculum.

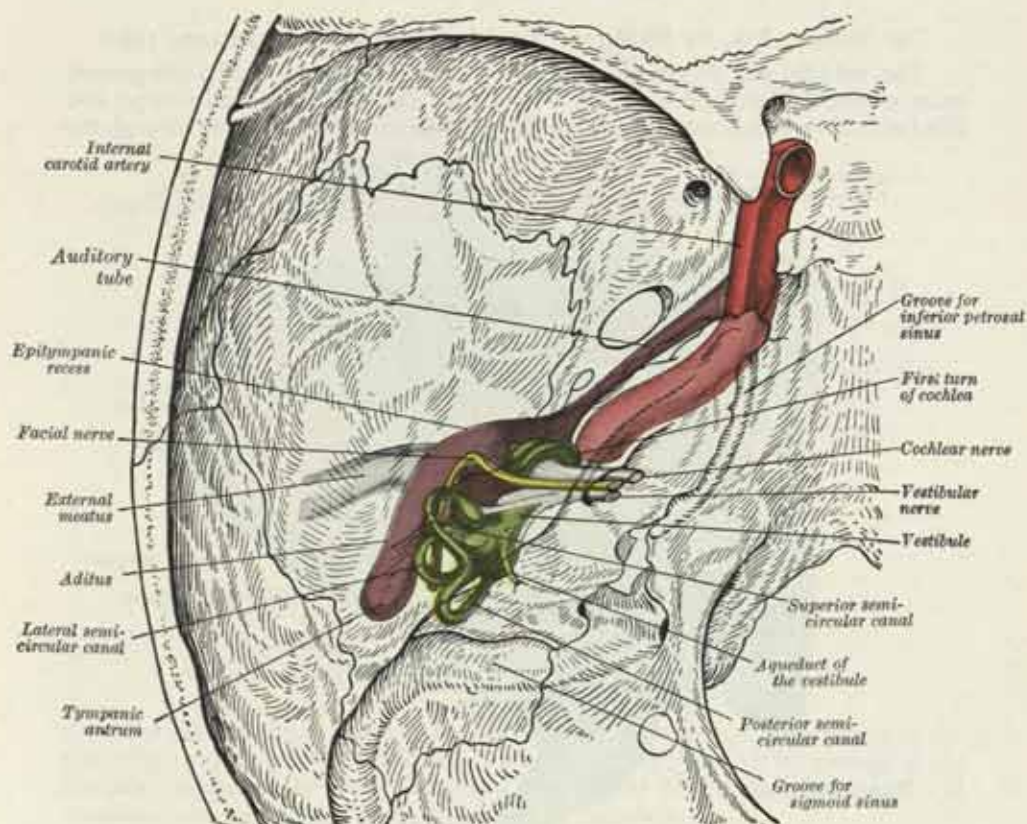


Examination of the external acoustic meatus.—The meatus can be examined most satisfactorily by light reflected down a funnel-shaped speculum, when the greater part of the canal and tympanic membrane can be brought into view. In using this instrument, it is advisable that the auricle should be drawn upwards, backwards, and a little laterally, so as to render the meatus as straight as possible.

At the point of junction of the osseous and cartilaginous portions an obtuse angle, which projects into the tube at its antero-inferior wall, is formed; this produces a sort of constriction, and renders it a narrow portion of the meatus—an important point to be remembered in connexion with the presence of foreign bodies in the meatus. The shortness of the meatus in children should be borne in mind when an aural speculum is

introduced, so that it be not pushed in too far, at the risk of injuring the tympanic membrane; indeed even in the adult the speculum should not be introduced beyond the constriction which marks the junction of the osseous and cartilaginous portions. Just in front of the membrane there is a well-marked depression, situated on the floor of the meatus, and bounded by a somewhat prominent ridge; in this foreign bodies may become lodged. By aid of the speculum, combined with traction of the auricle upwards and backwards, the greater part of the tympanic membrane is rendered visible (fig. 1047). It is a pearly-grey membrane, slightly glistening in the adult, placed obliquely, so as to form with the floor of the meatus a very acute angle (about fifty-five degrees), while with the roof it forms an obtuse angle. At birth it is more horizontal, situated in

FIG. 1048.—Scheme showing the parts of the left ear as if viewed through a semi-transparent temporal bone. Compare with figs. 1046 and 1052.



almost the same plane as the base of the skull. A reddish-yellow streak can be seen about midway between the anterior and posterior margins of the membrane, and extending from the centre obliquely upwards and forwards; this is the handle of the malleus, which is attached to the membrane. At the upper part of this streak, close to the roof of the meatus, a little white, round prominence is plainly to be seen; this is the lateral or short process of the malleus, projecting against the membrane. The tympanic membrane does not present a plane surface; on the contrary, its centre is drawn inwards, on account of its connexion with the manubrium of the malleus, the centre of the concavity corresponding to the *umbo* (p. 1272) on the deep surface of the membrane. A bright area of reflected light, known as the 'cone of light', is seen in the antero-inferior quadrant of the membrane. In front of, and behind, the short process of the malleus, the slightly marked anterior and posterior malleolar folds are seen, with the flaccid part of the tympanic membrane (p. 1272) between them. Behind and parallel to the upper part of the handle of the malleus, the long process of the incus is often seen as a whitish streak; sometimes it can be seen to end below in a round spot which is the head of the stapes.

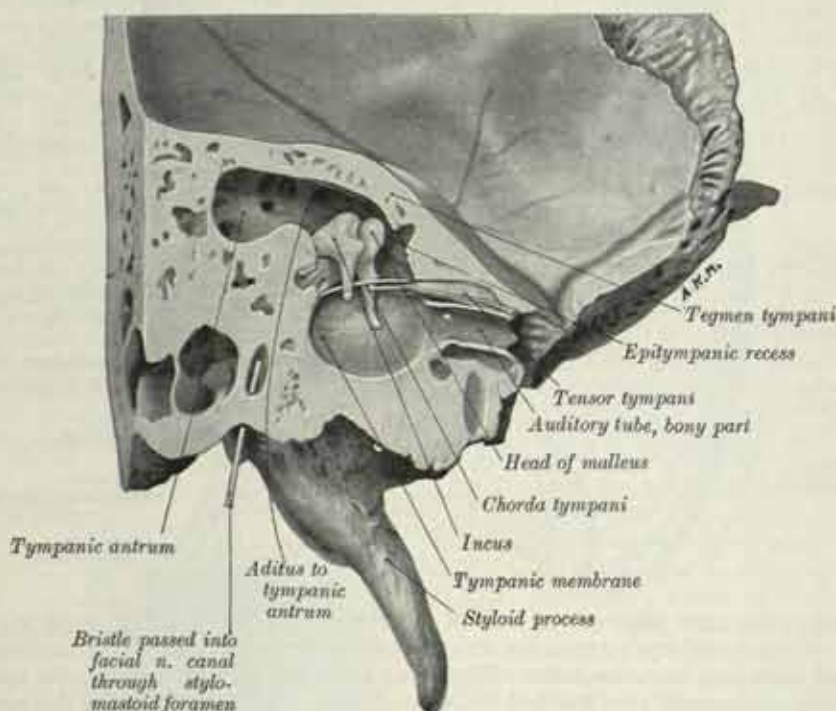
Applied Anatomy.—Malformations such as imperfect development of the external parts, supernumerary auricle, pre-auricular cysts, fistulae and sinuses, or absence of the meatus, are occasionally met with. In the child up to the age of 4 or 5 years there is a gap in the anteroinferior wall of the osseous part of the meatus, which is filled by membrane (foramen of Huschke, p. 327); it may persist in the adult.

The connexions of the nerves of the meatus explain the occurrence of reflex coughing and sneezing, from implication of the vagus, when there exists any source of irritation in the meatus, and the vomiting which may follow syringing the ears of children, and the occasional heart failure similarly induced in elderly people. No doubt also the association of earache with toothache or with cancer of the tongue is due to implication of the mandibular branch of the trigeminal nerve, which supplies the teeth and the tongue also. The upper half of the tympanic membrane is much more vascular than the lower half; for this reason, and also to avoid the chorda tympani nerve and ossicles, incisions through the membrane should be made at the lower and posterior part.

THE MIDDLE EAR, OR TYMPANIC CAVITY (figs. 1046, 1048-1050 and 1052)

The **middle ear** or **tympanic cavity**, is an irregular, laterally compressed space within the temporal bone. It is lined with mucous membrane (p. 1279) and filled with air, which is conveyed to it from the nasal part of the pharynx through the

FIG. 1049.—An oblique section through the left temporal bone, to show the lateral wall of the middle ear, and the tympanic antrum.



auditory tube. It contains a chain of movable bones, which connect its lateral to its medial wall and transmit the vibrations of the tympanic membrane across the cavity to the internal ear.

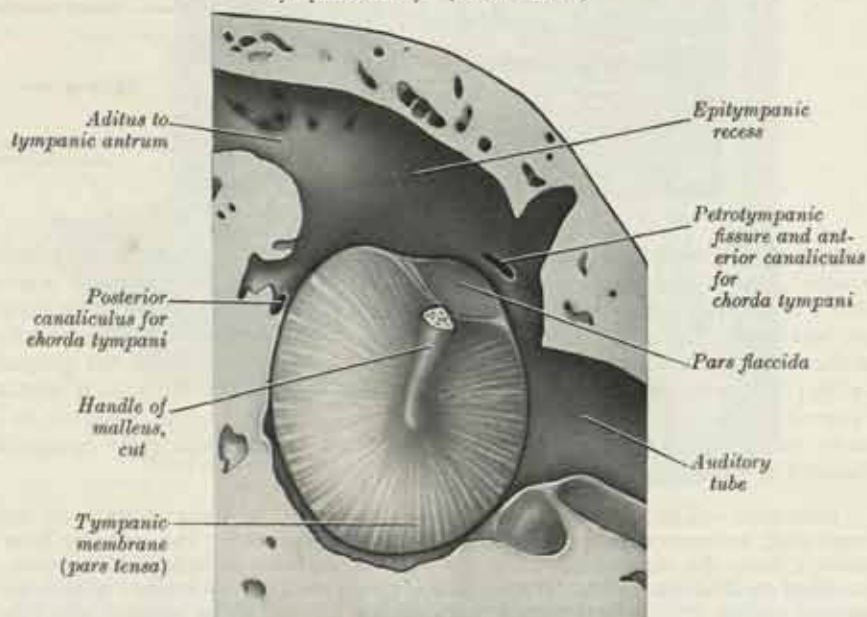
The tympanic cavity consists of two parts: the *tympanic cavity proper*, opposite the tympanic membrane, and the *epitympanic recess*, above the level of the membrane; the latter contains the upper half of the malleus and the greater part of the incus. Including the epitympanic recess, the vertical and anteroposterior diameters of the cavity are each about 15 mm. The transverse diameter measures about 6 mm. above and 4 mm. below; opposite the centre of the tympanic membrane it is only about 2 mm. The tympanic cavity is bounded laterally by the tympanic membrane; medially, by the lateral wall of the internal ear; it communicates, behind, with the

tympanic antrum and through it with the mastoid air-cells, and in front with the auditory tube (fig. 1048).

The **roof** of the tympanic cavity (fig. 1049) is formed by a thin plate of bone, named the *tegmen tympani*, which separates the cranial and tympanic cavities, and forms the greater part of the anterior surface of the petrous portion of the temporal bone; it is prolonged backwards so as to roof the tympanic antrum, and forwards to cover the canal for the Tensor tympani muscle. In the young child the unossified petrosquamosal suture (p. 325) may allow direct spread of infection from the tympanum to the cerebral meninges. In the adult, veins from the tympanum pass through this suture to the superior petrosal sinus, or the petrosquamous sinus if present (p. 849), and may transmit infection to the intracranial sinuses.

The **floor** is narrow, and consists of a thin, convex plate of bone which separates the tympanic cavity from the superior bulb of the internal jugular vein (fig. 1052); in places this bony wall may be deficient, and then the tympanic cavity is separated

FIG. 1050.—The lateral wall of the left tympanic cavity. (After Testut.)



from the vein by mucous membrane and fibrous tissue only. In the floor of the tympanic cavity, near the medial wall, there is a small aperture for the passage of the tympanic branch of the glossopharyngeal nerve. The floor is sometimes thick and contains some accessory mastoid air-cells.

The **lateral wall** of the tympanic cavity (figs. 1049 and 1050) is formed mainly by the tympanic membrane, but partly by the ring of bone in which this membrane is attached. There is a deficiency or notch in the upper part of the ring, close to which are three small apertures, viz.: the anterior and posterior canaliculi for the chorda tympani nerve and the petrotympanic fissure.

The *posterior canaliculus for the chorda tympani nerve* is situated in the angle of junction between the posterior and lateral walls of the tympanic cavity immediately behind the tympanic membrane and on a level with the upper end of the handle of the malleus; it leads into a minute canal, which descends in front of the canal for the facial nerve, and ends in that canal about 6 mm. above the stylomastoid foramen. Through it the chorda tympani nerve and a branch of the stylomastoid artery enter the tympanic cavity.

The *petrotympanic fissure* opens just above and in front of the ring of bone into which the tympanic membrane is inserted; in this situation it is a mere slit about 2 mm. in length. It lodges the anterior process and anterior ligament of the malleus, and transmits to the tympanic cavity the anterior tympanic branch of the maxillary artery.

The *anterior canaliculus for the chorda tympani nerve* is placed at the medial end of the petrotympanic fissure; through it the chorda tympani nerve leaves the tympanic cavity.

The **tympanic membrane** (figs. 1049, 1050) separates the tympanic cavity from the external acoustic meatus. It is thin and semi-transparent, nearly oval in form, somewhat broader above than below, and placed very obliquely, forming an angle of about fifty-five degrees with the floor of the meatus. Its longest diameter is downwards and forwards, and measures from 9 to 10 mm.; its shortest diameter from 8 to 9 mm. The greater part of its circumference is thickened, and forms a *fibrocartilaginous ring* which is fixed in the *tympanic sulcus* at the medial end of the meatus. This sulcus is deficient superiorly, and from the ends of the notch two bands, termed the *anterior* and *posterior malleolar folds*, are prolonged to the lateral

FIG. 1051.—A section of the tympanic membrane from the specimen shown in fig. 1064.



process of the malleus. The small, somewhat triangular part of the membrane situated above these folds is lax and thin, and is named the *pars flaccida*; a small orifice is sometimes seen in it. The chief part of the membrane is taut and is named the *pars tensa*. The manubrium of the malleus is firmly attached to the inner surface of the tympanic membrane as far as its centre, which projects towards the tympanic cavity; the inner surface of the membrane is thus convex, and the point of greatest convexity is named the *umbo*. Although the membrane as a whole is convex on its inner surface, its radiating fibres (*vide infra*) are curved with their concavities directed inwards.

Structure.—The tympanic membrane is composed of three strata: an outer (cuticular), an intermediate (fibrous), and an inner (mucous). The *cuticular layer* is derived from the skin which lines the external acoustic meatus, and consists of stratified epithelium. The *fibrous stratum* consists of two layers: a superficial layer of radiate fibres which diverge from the manubrium of the malleus, and a deep layer of circular fibres, which are plentiful around the circumference, but sparse and scattered near the centre, of the membrane. Branched or dendritic fibres are also present, especially in the posterior half of the membrane. The *mucous layer* is a part of the mucous membrane of the tympanic cavity; it is thickest towards the upper part of the membrane, and is covered by a layer of ciliated columnar epithelium (fig. 1051). In the flaccid part of the tympanic membrane the fibrous stratum is replaced by loose connective tissue.

Vessels and Nerves.—The *arteries* of the tympanic membrane are derived from the deep auricular branch of the maxillary artery, which ramifies beneath the cuticular stratum; and from the stylomastoid branch of the posterior auricular artery, and tympanic branch of the maxillary artery, which are distributed to the mucous surface. The superficial *veins* open into the external jugular vein; those on the deep surface drain partly into the transverse sinus and veins of the dura mater, and partly into the plexus of veins on the auditory tube. The membrane receives its *nerve-supply* from the auriculotemporal branch of the mandibular nerve, the auricular branch of the vagus nerve, and the tympanic branch of the glossopharyngeal nerve.

The **medial wall** (fig. 1052) of the tympanic cavity is formed by the lateral wall of the internal ear. It presents for examination the promontory, the fenestra vestibuli, the fenestra cochleæ and the prominence of the facial nerve canal.

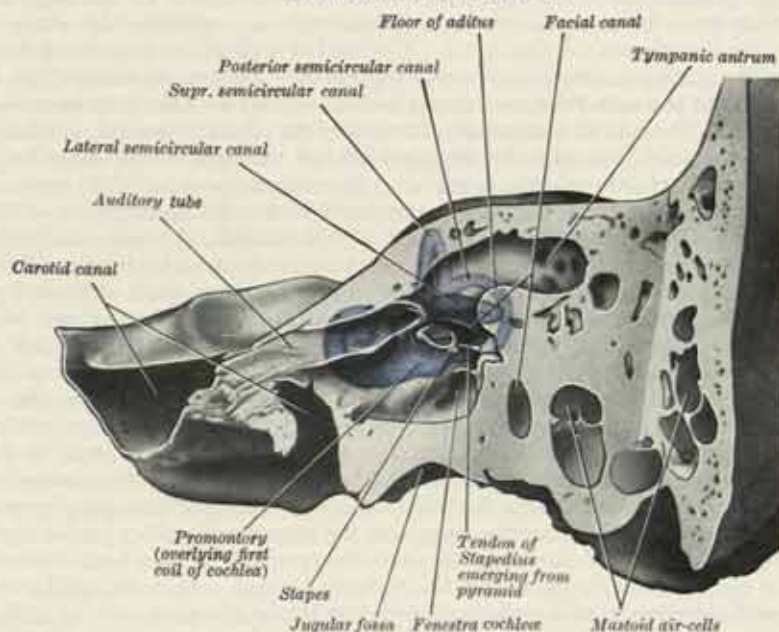
The *promontory* is a rounded prominence furrowed by small grooves which lodge the nerves of the tympanic plexus. It is formed by the projection outwards of the first turn of the cochlea. A minute spicule of bone frequently connects the promontory to the pyramid on the posterior wall. In front of the promontory the

apex of the cochlea is closely related to the medial wall of the tympanum (figs. 1048 and 1052).

The *fenestra vestibuli* is a reniform opening, situated above and behind the promontory, and leading from the tympanic cavity into the vestibule of the internal ear; its long diameter is horizontal, and its convex border is directed upwards. In the recent state it is occupied by the base of the stapes, the circumference of which is fixed to the margin of the fenestra by the annular ligament.

The *fenestra cochleæ* is situated below and a little behind the fenestra vestibuli, from which it is separated by the posterior part of the promontory. It lies completely under cover of the overhanging edge of the promontory in a deep hollow or niche.

FIG. 1052.—An oblique section through the left temporal bone, to show the medial wall of the middle ear.



The cochlea and the semicircular canals are outlined in blue.

Note the relationship of the first coil of the cochlea to the promontory, and the relationships of the facial nerve canal and the lateral semicircular canal to the medial wall of the aditus.

It is placed very obliquely, and, in the macerated bone, opens upwards and forwards from the tympanic cavity into the scala tympani of the cochlea. In the recent state it is closed by the *secondary tympanic membrane*, which is somewhat concave towards the tympanic cavity and convex towards the cochlea, the membrane being bent so that its posterosuperior one-third forms an angle with its antero-inferior two-thirds. This membrane consists of three layers: an external, derived from the mucous lining of the tympanic cavity; an internal, from the lining membrane of the cochlea; and an intermediate, fibrous, layer.

The *prominence of the facial nerve canal* indicates the position of the upper part of the bony canal in which the facial nerve is contained; this canal, the wall of which may be partly deficient, traverses the medial wall of the tympanic cavity from before backwards, immediately above the fenestra vestibuli, and then curves downwards in the posterior wall.

The **posterior wall** of the tympanic cavity (fig. 1052) is wider above than below, and presents for examination the entrance to the tympanic antrum, the pyramid and the fossa incudis.

The *aditus to the tympanic antrum* is a large irregular aperture, which leads backwards from the epitympanic recess into the upper part of an air-sinus, named the *tympanic antrum*. On the medial wall of the entrance to the antrum there is a rounded eminence, situated above and behind the prominence of the facial nerve canal; it corresponds with the position of the lateral semicircular canal.

The *pyramid* is situated immediately behind the fenestra vestibuli, and in front of the vertical portion of the facial nerve canal; it is hollow, and contains the Stapedius muscle; its summit projects forwards towards the fenestra vestibuli, and is pierced by a small aperture which transmits the tendon of the muscle. The cavity in the pyramid is prolonged downwards and backwards in front of the facial nerve canal, and communicates with the latter by an aperture which transmits a twig from the facial nerve to the Stapedius muscle.

The *fossa incudis* is a small depression in the lower and posterior part of the epitympanic recess; it lodges the short process of the incus, which is fixed to the fossa by ligamentous fibres.

The *tympanic antrum* (figs. 1046, 1048, 1049, 1050, 1052) is an air-sinus in the petrous part of the temporal bone. Its topographical relations are of great importance to the surgeon. On the upper part of its anterior wall is an opening, the *aditus*, which leads forwards into the epitympanic recess; medially, the aditus is related to the lateral semicircular canal. The medial wall of the antrum itself is related to the posterior semicircular canal (fig. 1048). Posteriorly the antrum is closely related to the sigmoid sinus; some of the mastoid air-cells may intervene between them. The roof of the antrum, formed by the tegmen tympani, is related to the middle cranial fossa and the temporal lobe of the brain. The floor has a number of apertures through which the antrum communicates with the mastoid air-cells. Antero-inferiorly, the antrum is related to the descending part of the canal for the facial nerve. The lateral wall of the antrum, through which the surgeon usually approaches the cavity, is formed by the postmeatal process of the squamous part of the temporal bone. This wall is only 2 mm. thick at birth, but increases in thickness at the rate of approximately 1 mm. a year, attaining a final thickness of 12–15 mm. The lateral wall of the antrum in the adult corresponds to the suprameatal triangle on the outer surface of the skull (pp. 278, 320); it lies beneath and can be felt through the cyma conchæ (p. 1264). The upper side of the triangle, formed by the supramastoid crest, is on a level with the floor of the middle cranial fossa; the front side, formed by the posterosuperior margin of the orifice of the external acoustic meatus, lies approximately along the course of the descending part of the canal for the facial nerve; and the posterior side, formed by a vertical tangent to the posterior margin of the meatal orifice, lies just in front of the course of the sigmoid sinus. In the adult, the tympanic antrum has a capacity of about 1 c.c., each of its diameters being about 10 mm. At birth, unlike the other cranial air-sinuses, it is well-developed and almost the same size as in the adult; it lies at a higher level in relation to the external acoustic meatus than in the adult. In the very young child, owing to the thinness of the lateral wall of the antrum and the absence or feeble development of the mastoid process, the stylo-mastoid foramen and the emerging facial nerve are very superficially situated.

The *mastoid air-cells* (Plates III and IV, figs. 1046, 1052) vary considerably in number, form and size in different individuals. In general, they form a series of intercommunicating cavities, lined by mucous membrane, with a flattened non-ciliated epithelium, continuous with that of the tympanic antrum and tympanic cavity. In some cases they extend throughout the mastoid process, even to its tip, and some of the cells may be separated from the sigmoid sinus and the posterior cranial fossa by extremely thin bone, which occasionally shows deficiencies. Some of the cells may lie superficial to, and even behind the sigmoid sinus, and others may lie in the posterior wall of the descending part of the canal for the facial nerve. Those contained in the squamous part of the temporal bone may sometimes be separated from the deeper cells in the petrous part by a plate of bone lying in the situation of the squamo-mastoid suture of early life. In other cases, the cells only extend very slightly into the mastoid process, and the mastoid consists largely either of dense bone or of cancellous bone containing bone marrow. All varieties of mastoid process occur, with varying mixtures of the above structures, and three types of mastoid are described, namely, pneumatic (containing many air-cells), sclerotic (with few or no air-cells) and mixed (containing air-cells and bone marrow). The cells may extend beyond the confines of the mastoid process. They may extend for some distance into the squamous part of the temporal bone above the supramastoid crest, and also into the posterior root of the zygoma. Others may extend forwards into the roof of the osseous part of the external acoustic meatus, lying immediately below the middle cranial fossa. Some may extend into the floor

of the tympanic cavity, lying in very close relation to the superior jugular bulb. Rarely a few cells may excavate the jugular process of the occipital bone. An important group of cellules may extend medially into the petrous part of the temporal bone, reaching even as far as its tip, and related to the auditory tube, the carotid canal, the labyrinth and the abducent nerve. Some investigators maintain that these petrous cells are not directly continuous with the mastoid cells proper, but are independent outgrowths from the tympanic cavity. The extensions of the mastoid air-cells described above are of considerable importance to the clinician. Infection of the cells may spread to the structures mentioned above as related to them. Whereas the tympanic antrum is well-developed at birth, the mastoid air-cells at this time are only just beginning to develop as tiny diverticula from the antrum. As the mastoid process begins to develop in the second year, the cells gradually extend into it, and by the fourth year they are well formed, though their greatest growth occurs at about the age of puberty. In about 20 per cent of cases the mastoid process is not excavated by air-cells.

The **anterior wall** of the tympanic cavity is constricted owing to the approximation of the medial and lateral walls of the cavity. Its lower and larger part consists of a thin lamina of bone which forms the posterior wall of the carotid canal, and is perforated by the superior and inferior caroticotympanic nerves, and the tympanic branch of the internal carotid artery. At the upper part of the anterior wall there are two canals, placed one above the other; the higher is the *canal for the Tensor tympani muscle*, the lower, the *bony part of the auditory tube*. These canals incline downwards and forwards, and open in the angle between the squamous and petrous parts of the temporal bone; they are separated by a thin, bony septum. The canal for the Tensor tympani and the septum run backwards on the medial wall of the tympanic cavity, and end immediately above the fenestra vestibuli, where the posterior end of the septum is curved laterally to form a pulley, named the *processus cochleariformis*, over which the tendon of the Tensor tympani bends in a lateral direction to reach its insertion into the upper part of the handle of the malleus.

The **auditory tube** (or *pharyngotympanic tube*) (figs. 1045, 1048, 1049) is the channel through which the tympanic cavity communicates with the nasal part of the pharynx. Through it air passes from the pharynx to the tympanic cavity and equalises the air-pressure on the inner and outer surfaces of the tympanic membrane. Its length is about 36 mm., and its direction is downwards, forwards and medially, forming an angle of about 45° with the sagittal plane and one of about 30° with the horizontal plane. It is formed partly of bone, partly of cartilage and fibrous tissue.

The **bony part** of the tube is about 12 mm. long. It begins in the anterior wall of the tympanic cavity, and, gradually narrowing, ends at the angle of junction of the squamous and petrous portions of the temporal bone, its extremity presenting a jagged margin which serves for the attachment of the cartilaginous part; the carotid canal lies on its medial side. It is oblong in transverse section with its greater diameter from side to side.

The **cartilaginous part** of the tube, about 24 mm. long, is formed of a triangular plate of cartilage, the greater part of which is situated in the posteromedial wall of the tube. The apex of the fibrocartilage is attached by fibrous tissue to the circumference of the medial end of the bony part of the tube, while its base lies directly under the mucous membrane of the lateral wall of the nasal part of the pharynx, where it forms an elevation, known as the *tubal elevation*, behind the pharyngeal orifice of the tube. The upper part of the cartilage is bent laterally and downwards, and the cartilage therefore consists of a broad *medial lamina*, and a narrow *lateral lamina*. On transverse section the cartilage has the appearance of a hook; the groove or furrow produced by the bending of the cartilage is open below and laterally, and this part of the wall of the canal is completed by fibrous membrane. The cartilage is fixed to the base of the skull in a groove between the petrous part of the temporal bone and the greater wing of the sphenoid bone; this groove ends near the root of the medial pterygoid plate. The cartilaginous and bony parts of the tube are not in the same plane, the former inclining downwards a little more than the latter. The diameter of the tube is greatest at the pharyngeal orifice, least at the junction of the bony and cartilaginous portions, and again increased towards the tympanic cavity; the narrowest part of the tube is termed the *isthmus*.

The mucous membrane of the tube is continuous in front with that of the

pharynx, and behind with that of the tympanic cavity; it is covered with ciliated columnar epithelium and is thin in the bony part, while in the cartilaginous part it contains many mucous glands, and near the pharyngeal orifice a considerable amount of lymphoid tissue, the *tube-tonsil*.

Relations.—Anterolaterally the Tensor veli palatini muscle separates the tube from the otic ganglion, the mandibular nerve and its branches, the chorda tympani nerve and the middle meningeal artery. This muscle receives some fibres from the lateral lamina of the cartilage and from the membranous part of the tube; these fibres constitute the *Dilatator tubæ* muscle. The Salpingopharyngeus (p. 1390) is attached to the lower part of the cartilage of the tube near its pharyngeal opening. Posteromedially the tube is related to the petrous part of the temporal bone and to the Levator veli palatini muscle, which arises partly from its medial lamina. The position and relations of the pharyngeal orifice are described with the nasal part of the pharynx (p. 1382).

The tube is opened during deglutition but the mechanism is uncertain. Some claim that the *Dilatator tubæ*, possibly aided by the Salpingopharyngeus, is responsible, though others deny the existence of the *Dilatator tubæ* muscle. It is also claimed that the Levator veli palatini, by elevating the cartilaginous part of the tube, allows the tube to open passively by releasing tension on the cartilage.

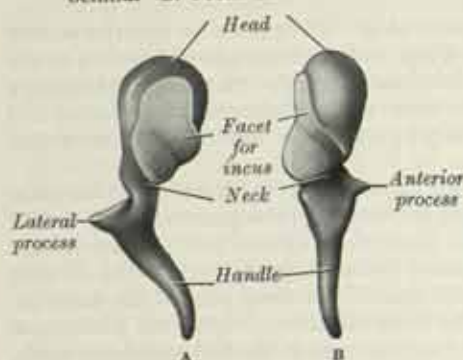
In the new-born child the auditory tube is about half as long as that of the adult. Its direction is more horizontal, and its bony part is relatively shorter, but much wider than in the adult. Its pharyngeal orifice is a narrow slit, which is on a level with the palate and is devoid of a tubal elevation.

Vessels and Nerves.—The arteries of the auditory tube are derived from the ascending pharyngeal branch of the external carotid artery and from two branches of the maxillary artery, viz.:—the middle meningeal artery and the artery of the pterygoid canal. The veins open into the pterygoid venous plexus. The nerves of the tube spring from the tympanic plexus (p. 1118) and from the pharyngeal branch of the pterygopalatine ganglion.

THE AUDITORY OSSICLES

The tympanic cavity contains a chain of three movable ossicles, the *malleus*, *incus*, and *stapes*. The malleus is attached to the tympanic membrane and the base of the stapes is attached to the circumference of the fenestra vestibuli, while the incus is placed between, and articulates with, the malleus and stapes.

FIG. 1053.—The left malleus. A. From behind. B. From the medial side.



The **malleus** (fig. 1053), so named from its fancied resemblance to a hammer, is from 8 to 9 mm. long, and is the largest of the auditory ossicles. It consists of a head, neck and three processes, viz. the manubrium or handle, and the anterior and lateral processes.

The **head**, which is the large upper end of the bone, is situated within the epitympanic recess; it is ovoid in shape, and articulates posteriorly with the incus, being free in the rest of its extent. The facet for articulation with

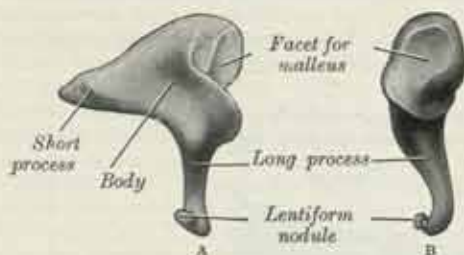
the incus is constricted near the middle, and consists of an upper larger and lower smaller part, situated nearly at right angles to each other. Opposite the constriction the lower margin of the facet projects in the form of a process, which is named the *cog-tooth* or *spur* of the malleus.

The **neck** is the contracted part just beneath the head; below the neck there is an enlargement to which the various processes are attached.

The **handle of the malleus** is connected by its lateral margin with the tympanic membrane. It is directed downwards, medially and backwards; it decreases in size towards its free end, which is curved slightly forwards and flattened transversely. Near the upper end of its medial surface there is a slight projection, into which the tendon of the Tensor tympani is inserted.

The *anterior process* is a delicate spicule, directed forwards from the enlargement below the neck; it is connected to the petrotympanic fissure by ligamentous fibres. In the fetus this is the longest process of the malleus, and it is continuous in front with the cartilage of Meckel (p. 118).

FIG. 1054.—The left incus. A. From the medial side. B. From in front.



The *lateral process* is a conical projection which springs from the root of the handle of the malleus; it is directed laterally, and is attached to the upper part of the tympanic membrane and, by means of the anterior and posterior malleolar folds, to the extremities of the notch at the upper part of the tympanic sulcus.

Ossification.—The malleus, with the exception of its anterior process, is ossified from a single centre, which appears near the neck of the bone in the fourth month of intrauterine life. The anterior process is ossified separately, in membrane, and joins the main part of the bone about the sixth month of fetal life.

The *incus* (fig. 1054) has received its name from its supposed resemblance to an anvil, but its shape is more like that of a premolar tooth, with two widely diverging roots. It consists of a body and two processes.

The *body* is somewhat cubical, but compressed laterally. On its anterior surface there is a saddle-shaped facet, for articulation with the head of the malleus.

FIG. 1055.—A. The left stapes. B. Medial surface of its base.



The *long process*, rather more than half the length of the handle of the malleus, descends nearly vertically, behind and parallel to that process; its lower end bends medially, and terminates in a rounded projection, named the *lentiform nodule*, the inner surface of which is covered with cartilage, and articulates with the head of the stapes.

The *short process*, somewhat conical in shape, projects backwards, and is attached by ligamentous fibres to the fossa incudis, in the lower and posterior part of the epitympanic recess.

Ossification.—The incus is ossified from one centre, which appears in the upper part of its long process in the fourth month of intrauterine life; the lentiform nodule may have a separate centre.

The *stapes* (fig. 1055), so called from its resemblance to a stirrup, consists of a head, neck, two limbs and a base.

The *head* is directed laterally, and on it there is a depression for articulation with the lentiform nodule of the incus.

The *neck* is the constricted part supporting the head; the tendon of the Stapedius muscle is inserted into its posterior surface.

The *limbs* diverge from the neck and are connected at their ends by a flattened oval plate, termed the *base*, which forms the footplate of the stirrup and is fixed to the margin of the fenestra vestibuli by a ring of ligamentous fibres. The anterior limb is shorter and less curved than the posterior.

Ossification.—The stapes is ossified from a single centre, which appears in the base of the bone in the fourth month of intrauterine life.

The articulations of the auditory ossicles.—The incudomalleolar joint is a saddle articulation. The incudostapedial joint is a 'ball-and-socket' articulation. Each is enveloped by an articular capsule containing a considerable amount of elastic tissue.*

The ligaments of the ossicles.—The ossicles are connected to the walls of the tympanic cavity by ligaments: three for the malleus, and one each for the incus and stapes.

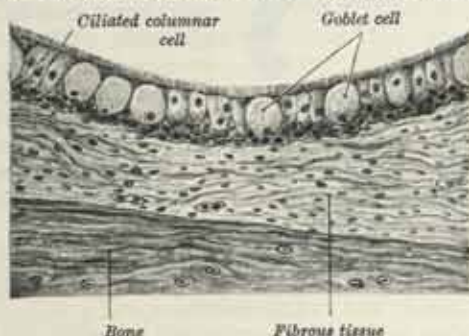
The *anterior ligament of the malleus* is attached by one end to the neck of the

*D. V. Davies and M. Hasty, *Journ. Laryn. and Otol.*, 62, 1948, p. 533.

malleus, just above the anterior process, and by the other to the anterior wall of the tympanic cavity, close to the petrotympanic fissure, some of its fibres being prolonged through the fissure to reach the spine of the sphenoid bone; some fibres are continued into the sphenomandibular ligament, both this ligament and the anterior ligament of the malleus being derived from the fibrous sheath of the cartilage of Meckel (p. 118). The ligament may contain muscle fibres (the *Laxator tympani* or *Musculus externus mallei*).

The *lateral ligament of the malleus* is a triangular band passing from the posterior part of the border of the tympanic notch to the head of the malleus.

FIG. 1056.—Mucous membrane of the tympanic cavity near the entrance of the auditory tube. From the specimen shown in fig. 1064.



The *superior ligament of the malleus* connects the head of the malleus to the roof of the epitympanic recess.

The *posterior ligament of the incus* connects the end of the short process of the incus to the fossa incudis.

The *superior ligament of the incus* is little more than a fold of mucous membrane, passing from the body of the incus to the roof of the epitympanic recess.

The vestibular surface and the circumference of the base of the stapes are covered with hyaline cartilage; that encircling the base is attached to the margin of the fenestra vestibuli by a ring of elastic fibres, termed the *annular ligament of the base of the stapes*. The posterior part of this ligament is much narrower than the anterior part, and acts as a kind of hinge on which the base of the stapes moves when the *Stapedius* muscle contracts.

The **muscles of the tympanic cavity** are the *Tensor tympani* and *Stapedius*.

The **Tensor tympani** (figs. 1045, 1049) is contained in the bony canal above the bony part of the auditory tube, from which it is separated by a thin bony septum. It arises from the cartilaginous portion of the auditory tube and the adjoining part of the greater wing of the sphenoid, as well as from the bony canal in which it is contained. Passing backwards through the canal, it ends in a slender tendon which bends laterally round the pulley-like *processus cochleariformis*, and is inserted into the handle of the malleus, near its root.

Nerve-supply.—The *Tensor tympani* is supplied by a branch of the nerve to the Medial pterygoid muscle, which in its turn is a branch of the mandibular nerve, and traverses the otic ganglion without interruption (p. 1108).

The **Stapedius** arises from the wall of a conical cavity in the pyramid and from the continuation of this cavity which passes down in front of the descending part of the canal for the facial nerve (p. 1274); its tendon emerges from the orifice at the apex of the pyramid, and, passing forwards, is inserted into the posterior surface of the neck of the stapes.

Nerve-supply.—The *Stapedius* is supplied by a branch of the facial nerve.

Actions.—Under normal conditions, the *Tensor tympani* and the *Stapedius* contract simultaneously and reflexly in response to sounds of fairly high intensity, exerting "a protective damping effect upon sound vibrations reaching the internal ear".* The *Tensor* on contraction pulls inwards the tympanic membrane and renders it more tense; its action also results in the base of the stapes being pushed more tightly into the fenestra vestibuli. The *Stapedius* opposes the latter action of the *Tensor*.

Movements of the auditory ossicles.—The handle of the malleus follows all the movements of the tympanic membrane, while the malleus and incus rotate together around an axis which runs through the short process of the incus and the anterior liga-

* C. S. Hallpike, "On the Function of the Tympanic Muscles," *Proc. Roy. Soc. Med.*, 28, 1935.

ment of the malleus. When the tympanic membrane and the handle of the malleus move inwards, the long process of the incus also moves in the same direction and pushes the base of the stapes towards the labyrinth. This motion is communicated to the fluid (perilymph) contained within the labyrinth and the movement of the perilymph causes an outward bulging of the secondary tympanic membrane which closes the fenestra cochleæ. The conditions are reversed when the tympanic membrane moves in an outward direction, but if this movement of the membrane be exaggerated the incus does not follow the full outward excursion of the malleus, but merely glides on this bone at the incudomalleolar joint, and thus the danger of pulling the base of the stapes out of the fenestra vestibuli is avoided. When the handle of the malleus is carried inwards, the cog-tooth or spur on the lower margin of the head of the malleus locks the incudomalleolar joint, and this necessitates an inward movement of the long process of the incus; the joint is unlocked when the handle of the malleus is carried outwards. The three bones collectively act as a bent lever, so that the base of the stapes does not move in and out of the fenestra vestibuli like a piston, but rocks on a fulcrum which is situated on the lower border of the fenestra, and at this site the annular ligament is thickened.

The **mucous membrane of the tympanic cavity** is continuous with that of the pharynx, through the auditory tube. It invests the auditory ossicles and the muscles and nerves contained in the tympanic cavity, forms the inner layer of the tympanic membrane and the outer layer of the secondary tympanic membrane, and lines the tympanic antrum and mastoid air-cells. It forms several vascular folds which extend from the walls of the tympanic cavity to the ossicles; of these, one descends from the roof of the cavity to the head of the malleus and upper margin of the body of the incus, and a second invests the Stapedius muscle; other folds invest the chorda tympani nerve and the Tensor tympani muscle. These folds separate off pouch-like recesses, and give the interior of the tympanum a somewhat honeycombed appearance. One of these pouches, termed the *superior recess of the tympanic membrane*, lies between the neck of the malleus and the pars flaccida. Two other recesses, termed the *anterior* and *posterior recesses of the tympanic membrane*, may be mentioned: they are formed by the mucous membrane which envelops the chorda tympani nerve, and are situated, one in front of, and the other behind, the handle of the malleus. In the tympanic cavity the mucous membrane is pale, thin and slightly vascular. It is covered with ciliated columnar epithelium except over the posterior part of the medial wall, the posterior wall and the auditory ossicles where the cells are flatter and nonciliated. Near the orifice of the auditory tube numerous goblet cells are present, but apart from this there are no mucous glands (fig. 1056). The tympanic antrum and the mastoid air-cells are lined by a flattened nonciliated epithelium. It is to be noted that the tympanic cavity and tympanic antrum, the auditory ossicles and the structures comprising the internal ear are more or less fully developed by birth and undergo little subsequent alteration. In the fœtus the tympanic cavity contains a jelly-like tissue, which has practically disappeared by birth, at which time the cavity is filled with a fluid that is absorbed after birth when air enters the cavity through the auditory tube.

Vessels and Nerves.—The *arteries* are six in number. Two of them are larger than the others, viz. the anterior tympanic branch of the maxillary artery, which supplies the tympanic membrane, and the stylomastoid branch of the posterior auricular artery, which supplies the posterior part of the tympanic cavity and mastoid air-cells. The smaller arteries are—the petrosal branch of the middle meningeal artery, which enters through the hiatus for the greater petrosal nerve; the superior tympanic branch of the middle meningeal artery, which traverses the canal for the Tensor tympani; a branch from the ascending pharyngeal artery, and another from the artery of the pterygoid canal, which accompany the auditory tube; and the tympanic branch from the internal carotid artery, given off in the carotid canal and perforating the thin anterior wall of the tympanic cavity. In early fœtal life the stapedial artery passes through the ring of the stapes (p. 169). The *veins* terminate in the pterygoid venous plexus and in the superior petrosal sinus. From the mucous membrane of the tympanic antrum a small group of veins runs medially through the arch formed by the superior semicircular canal. They emerge on the posterior surface of the petrous part of the temporal bone through the subarcuate fossa, and open into the superior petrosal sinus. These small veins are the remains of the large subarcuate veins of the child, and constitute a pathway of infection from the tympanic antrum to the meninges of the brain. The *lymph vessels* are described on page 889. The *nerves* constitute the tympanic plexus, which ramifies upon the surface of the promontory. The plexus is

formed by (1) the tympanic branch of the glossopharyngeal nerve, and (2) the caroticotympanic nerves.

The *tympanic branch of the glossopharyngeal* enters the tympanic cavity by the *canaliculus for the tympanic nerve*, and divides into branches which ramify on the promontory and enter into the formation of the tympanic plexus. The *superior and inferior caroticotympanic nerves*, from the carotid plexus of the sympathetic, pass through the wall of the carotid canal, and join the plexus. The tympanic plexus supplies, (a) branches to the mucous lining of the tympanic cavity, auditory tube, and mastoid air-cells; (b) a branch which goes through an opening in front of the fenestra vestibuli and joins the greater petrosal nerve; and (c) the *lesser petrosal nerve*, which may be looked upon as the continuation of the tympanic branch of the glossopharyngeal nerve through the tympanic plexus. The lesser petrosal nerve traverses a small canal below the canal for the Tensor tympani, runs past, and receives a connecting branch from the ganglion of the facial nerve, and reaches the anterior surface of the temporal bone through a small opening on the lateral side of the hiatus for the greater petrosal nerve. It then passes through the foramen ovale or the emissary sphenoidal foramen (p. 316 *) and joins the otic ganglion (p. 1129). Postganglionic fibres pass from the otic ganglion, via the auriculo-temporal nerve, to provide the secreto-motor supply for the parotid gland.

The *chorda tympani nerve* is given off from the facial nerve, about 6 mm. before that nerve emerges from the stylomastoid foramen. It runs upwards and forwards in a canal, and enters the tympanic cavity through the *posterior canaliculus*. It then runs forwards in the substance of the tympanic membrane lying between the mucous and fibrous layers (p. 1272). After crossing the upper part of the handle of the malleus it reaches the anterior wall, and passes through the *anterior canaliculus*.

The *nervus spinosus* (p. 1108), a branch of the mandibular nerve, supplies branches to the mastoid air-cells.

Applied Anatomy.—Fractures of the middle fossa of the base of the skull almost invariably involve the tympanic roof, and are accompanied by a rupture of the tympanic membrane or fracture through the roof of the bony meatus. They are associated with continued bleeding from the ear, and, if the dura mater has also been torn, with discharge of cerebrospinal fluid.

The tympanic cavity is frequently the seat of disease, both suppurative and non-suppurative, and in practically every case the inflammation spreads upwards from the nose or throat along the auditory tube. Acute inflammatory troubles spreading up to the tympanic cavity are usually associated with so much inflammatory swelling of the mucous membrane of the tube as to occlude it, and thus the products of inflammation are pent up in the tympanic cavity and directly involve the tympanic antrum. In such circumstances the only means of escape for the products is by rupture of the tympanic membrane, which usually occurs spontaneously and is followed by a free discharge of pus, with relief from the acute pain which exists in this condition. Should the swelling of the walls of the auditory tube then subside, the normal drainage of the cavity will be established and the perforation in the drum will heal, but if not—as is often the case because the opening of the tube may be occluded by adenoid growths in the nasal part of the pharynx or other cause—the pus will continue to accumulate in the middle ear and will overflow through the perforation as a chronic otorrhœa. Several intracranial complications are often produced owing to purulent material being retained; thus an abscess may form between the bone and dura mater, (a) above the roof of the tympanic cavity, and immediately beneath the dura covering the temporal lobe of the brain, or (b) between the deep aspect of the mastoid process and the sigmoid sinus, possibly extending widely and surrounding the sinus. In this latter type of case thrombosis of the sinus readily occurs, and the clot being also infected tends to disintegrate and be carried into the general circulation, particles becoming lodged in the capillaries of the lungs and setting up abscesses therein. In addition, bone disease of the tympanic cavity or antrum may be associated with severe and fatal septic meningitis, or with the formation of abscess in the brain, the most common sites being the temporal lobe and the hemisphere of the cerebellum.

In some cases of chronic bone disease in the tympanic cavity, the facial nerve becomes exposed as it lies in its canal and an inflammatory process is set up in the nerve, leading to facial paralysis of the infranuclear or peripheral type (p. 1122).

THE INTERNAL EAR

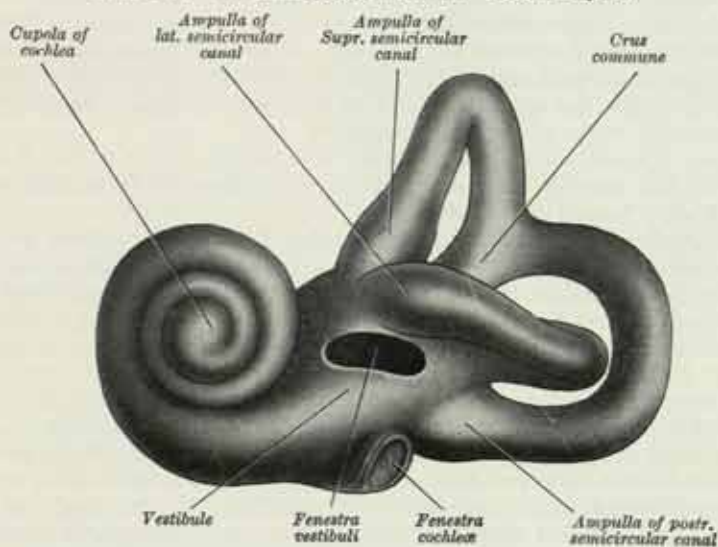
The **internal ear** is the essential part of the organ of hearing. It consists of two parts: (a) the *bony labyrinth*, a series of cavities within the petrous part of the temporal bone, and (b) the *membranous labyrinth*, a series of communicating membranous sacs and ducts, contained within the bony cavities.

THE BONY LABYRINTH (figs. 1048, 1057, 1058)

The **bony labyrinth** consists of three parts: the *vestibule*, the *semicircular canals* and the *cochlea*. These are cavities hollowed out of the substance of the bone, and lined by periosteum; they contain a clear fluid, known as the perilymph, in which the membranous labyrinth is placed. The bony labyrinth consists of harder, denser bone than the surrounding parts of the petrous portion of the temporal bone, so that it is possible, particularly in the very young skull, to separate the labyrinth from the petrous temporal (fig. 1057).

The **vestibule** is the central part of the bony labyrinth, and is situated medial to the tympanic cavity, behind the cochlea and in front of the semicircular canals. It is somewhat ovoid in shape, but flattened transversely; it measures about 5 mm. from before backwards the same from above downwards, and about 3 mm. across. In its *lateral wall* there is the opening of the fenestra vestibuli, closed in the recent state by the base of the stapes and its annular ligament. On the front part of the *medial wall* there is a small *spherical recess*, which lodges the saccule, and is perforated by several minute holes (*macula cribrosa media*). The recess corresponds to the

FIG. 1057.—The left osseous labyrinth. Lateral aspect.



inferior vestibular area in the bottom of the internal acoustic meatus, and the foramina transmit filaments of the eighth cranial nerve to the saccule. Behind this recess there is an oblique ridge, termed the *vestibular crest*, the anterior end of which is named the *pyramid of the vestibule*; this ridge divides below to enclose a small depression, the *cochlear recess*, which is perforated by a number of holes for the passage of filaments of the eighth cranial nerve to the vestibular end of the duct of the cochlea. Above and behind the vestibular crest, and situated in the *roof* and medial wall of the vestibule there is an *elliptical recess* which lodges the utricle. The pyramid and adjoining part of the elliptical recess are perforated by a number of holes (*macula cribrosa superior*); the holes in the pyramid transmit the nerves to the utricle, and those in the elliptical recess the nerves to the ampullae of the superior and lateral semicircular ducts. The pyramid and the adjoining part of the elliptical recess correspond to the superior vestibular area at the bottom of the internal acoustic meatus. The orifice of the *aqueduct of the vestibule* lies below the elliptical recess. This aqueduct extends to the posterior surface of the petrous portion of the temporal bone; it transmits a small vein, and contains a tubular prolongation of the membranous labyrinth which is termed the *endolymphatic duct*. At the *posterior part* of the vestibule there are the five orifices of the semicircular canals: at the *anterior part*, an elliptical opening leading into the scala vestibuli of the cochlea.

The **semicircular canals** are three in number, superior, posterior and lateral,

and are situated above and behind the vestibule. They are compressed from side to side, and each describes about two-thirds of a circle. They are unequal in length, but are all about 0.8 mm. in diameter; each presents a dilatation at one end, called the *ampulla*, the diameter of which is nearly twice that of the canal. They open into the vestibule by five orifices, one of which is common to two of the canals.

The *superior semicircular canal*, 15 to 20 mm. in length, is vertical in direction, and is placed transversely to the long axis of the petrous portion of the temporal bone, on the anterior surface of which its arch forms the arcuate eminence (p. 324). Some maintain that the arcuate eminence does not accurately coincide with the superior semicircular canal but lies in the course of the occipito-temporal sulcus on the inferior surface of the temporal lobe of the cerebral hemisphere. Its antero-lateral end is ampullated, and opens into the upper and lateral part of the vestibule; the opposite end unites with the upper end of the posterior canal to form the *crus commune*, which is about 4 mm. long, and opens into the medial part of the vestibule.

The *posterior semicircular canal*, also vertical, is directed backwards, nearly parallel with the posterior surface of the petrous bone; it is from 18 mm. to 22 mm. long; its ampullated end opens into the lower part of the vestibule, where there are several small holes (*macula cribrosa inferior*) for the transmission of the nerves to this ampulla, their position corresponding to the *foramen singulare* in the bottom of the internal acoustic meatus. Its upper end opens into the *crus commune*.

The *lateral or horizontal canal* is from 12 mm. to 15 mm. long, and its arch is directed horizontally backwards and laterally. Its anterior or ampullated end opens into the upper and lateral angle of the vestibule, just above the fenestra vestibuli and immediately below the ampullated end of the superior canal; its posterior end opens below the orifice of the *crus commune*.

The lateral semicircular canal of one ear is in the same plane as that of the other ear; while the superior canal of one ear is in a plane nearly parallel with that of the posterior * canal of the other ear.

The *cochlea* (figs. 1048, 1061, 1064, 1065) bears a resemblance to the shell of the common snail; it forms the anterior part of the labyrinth, is conical in form, and placed in front of the vestibule; it measures about 5 mm. from base to apex, and its breadth across the base is about 9 mm. Its apex, or *cupola*, is directed forwards and laterally, with a slight inclination downwards, towards the upper and front part of the medial wall of the tympanic cavity (fig. 1048); its base is directed towards the bottom of the internal acoustic meatus, and is perforated by numerous apertures for the passage of the cochlear nerve. The cochlea † consists of a conical-shaped central axis, termed the *modiolus*; of a canal, wound spirally around the central axis for two turns and three-quarters; and of a delicate lamina, termed the *osseous spiral lamina*, which projects from the modiolus into the canal, and partially divides it. In the recent state the division of the canal is completed by the *basilar membrane*, which stretches from the free border of the osseous spiral lamina to the outer wall of the bony cochlea; the two passages into which the cochlear canal is thus divided communicate with each other at the apex of the modiolus by a small opening, named the *helicotrema*.

The *modiolus* is the conical, central axis or pillar of the cochlea. Its base is broad, and appears at the bottom of the internal acoustic meatus, where it corresponds with the *tractus spiralis foraminosus*, which is perforated by numerous orifices for the transmission of the branches of the cochlear nerve; the nerves for the first turn and a half of the cochlea pass through the foramina of the tractus spiralis foraminosus; those for the apical turn, through the *foramen centrale*. The canals of the tractus spiralis foraminosus pass through the modiolus and successively bend outwards to reach the attached margin of the osseous spiral lamina. Here they become enlarged, and by their apposition form the *spiral canal of the modiolus*, which follows the course of the attached margin of the osseous spiral lamina and lodges the spiral ganglion. The foramen centrale is continued into a canal which runs through the middle of the modiolus to its apex.

The bony canal of the cochlea takes two turns and three-quarters round the modiolus; the first turn bulges into the tympanic cavity and there gives rise to the promontory (p. 1272). It is about 30 mm. long, and diminishes gradually in

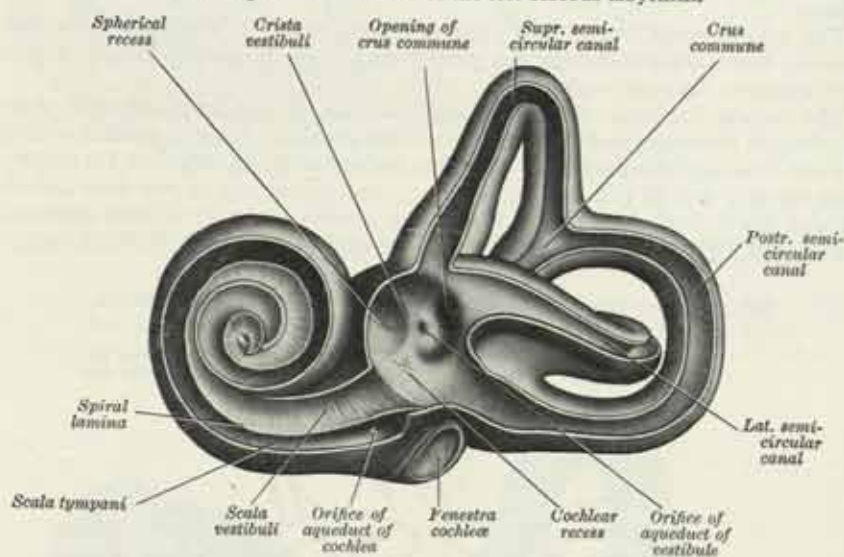
* E. W. Peet (*Proc. Phys. Society*, 1937) has shown that those planes are not actually parallel.

† In the description which follows, the cochlea is supposed to be resting on its base.

diameter from the base to the summit, where it ends in the *cupola*, which forms the apex of the cochlea. The beginning of this canal is about 3 mm. in diameter, and in it there are three openings. One—the *fenestra cochleæ*—communicates with the tympanic cavity and in the recent state is closed by the *secondary tympanic membrane*; another, of an elliptical form, opens into the vestibule. The third is the aperture of the aqueduct of the cochlea, leading to a minute funnel-shaped canal which opens on the inferior surface of the petrous part of the temporal bone (p. 324). It transmits a small vein to join the inferior petrosal sinus, and establishes a communication between the subarachnoid space and the *scala tympani*.

The *osseous spiral lamina* is a bony shelf or ledge which winds round and projects from the modiolus into the interior of the canal, like the thread of a screw. It reaches about halfway across the canal, and incompletely divides it into two passages or *scalæ*: an upper, named the *scala vestibuli*, and a lower, the *scala tympani*. The width of the osseous spiral lamina gradually decreases from the basal to the apical coil of the cochlea, and near the summit of the cochlea the lamina ends in a hook-shaped process, termed the *hamulus of the spiral lamina*; this assists in forming the boundary of the *helicotrema*, through which the two *scalæ* communicate with each

FIG. 1058.—The interior of the left osseous labyrinth.



other. From the spiral canal of the modiolus numerous canals pass outwards through the osseous spiral lamina as far as its free edge and transmit branches of the cochlear nerve. In the lower part of the first turn of the cochlea a *secondary spiral lamina* projects inwards from the outer wall of the bony tube; it does not, however, reach the osseous spiral lamina, so that if the laminae be viewed from the vestibule a narrow fissure, termed the *vestibular fissure*, is seen between them.

The *bony labyrinth* is lined by a thin fibroserous membrane which is closely adherent to the bone; the free surface of the membrane is smooth, and covered with a layer of epithelium. The bony labyrinth is filled with *perilymph*, a fluid identical in composition, and confluent with, the cerebrospinal fluid. Some investigators * maintain that cerebrospinal fluid and perilymph are not identical in composition, and that the aqueduct of the cochlea does not communicate directly with the subarachnoid space, a fibrous membrane intervening, so that any interchange between the cerebrospinal fluid and the perilymph would be by a process of diffusion. The part of the petrous bone which immediately surrounds the labyrinth is developed from the cartilaginous ear-capsule; it is denser than the rest of the petrous bone, and exhibits interglobular spaces, which contain cartilage cells (fig. 1062). The modiolus of the cochlea, on the other hand, is formed of spongy membrane-bone.† A tubular process of the lining membrane is prolonged through the aqueduct of the cochlea to the outer surface of the dura mater. The

* J. G. Waltner, *Arch. Otolaryngol.*, 1948, 47; S. H. Mygind, *Acta Otolaryngol.*, 1948, 68.

† J. S. Fraser and J. K. Milne Dickie, *J. Anat. and Physiol.*, 49, 1914.

perilymphatic space of the vestibule communicates behind with that of the semicircular canals, and opens anteriorly into the scala vestibuli of the cochlea, which in turn opens into the scala tympani through the helicotrema, at the apex of the cochlea. The scala tympani is separated from the tympanic cavity by the secondary tympanic membrane, but is continuous with the subarachnoid space through the aqueduct of the cochlea (*see above*).

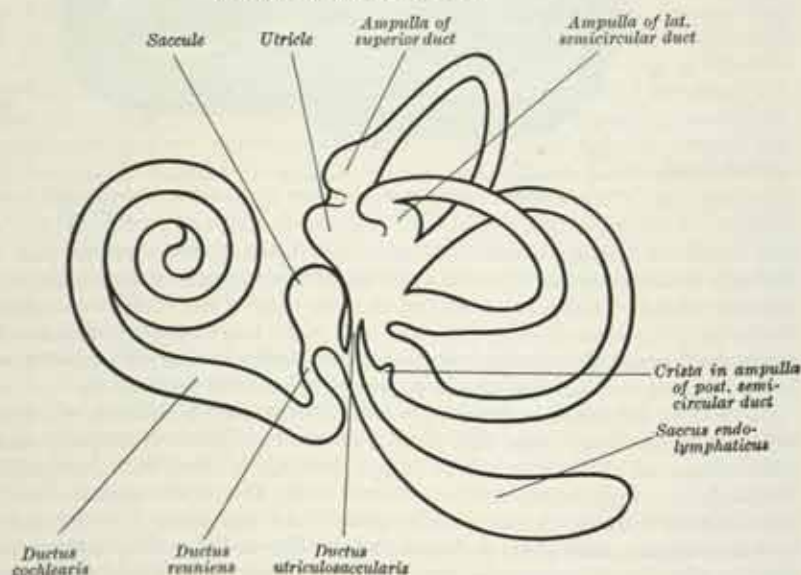
THE MEMBRANOUS LABYRINTH (figs. 1059 to 1061)

The **membranous labyrinth** is lodged within, but is much smaller than the bony labyrinth; it is filled with fluid named *endolymph*, and in its walls the branches of the eighth cranial nerve are distributed. It includes: (a) the *utricle* and *sacculle*, two small sacs, lodged in the vestibule; (b) three *semicircular ducts*, enclosed within the semicircular canals; and (c) the *duct of the cochlea*, contained within the bony cochlea. The various parts of the membranous labyrinth form a closed system of channels which, however, communicate freely with one another; the semicircular ducts open into the utricle, the utricle into the sacculle through the ductus utriculosaccularis, and the sacculle into the duct of the cochlea through the ductus reuniens.

The membranous labyrinth is fixed at certain points to the wall of the bony labyrinth, but is separated from the greater part of the bony labyrinth by a space which contains the perilymph.

The **utricle**, the larger of the two vestibular sacs, is irregularly oblong in shape, and occupies the upper and posterior part of the vestibule, lying in contact with the elliptical recess and the part below it. That portion which is lodged in the elliptical recess forms a sort of pouch or cul-de-sac; the lateral half of the floor and the adjoining lower part of the lateral wall of this is thickened over an area measuring about 3 mm. by 2 mm. to form the *macula of the utricle* (p. 1288), which receives

FIG. 1059.—A schematic representation of the membranous labyrinth.
(After J. K. Milne Dickie.)



the utricular filaments of the vestibular nerve. The ampullæ of the superior and lateral semicircular ducts open into the lateral part of the utricle, while the ampulla of the posterior duct, the crus commune and the posterior end of the lateral duct open into the medial part of the utricle. The posterior end of the lateral duct widens into a flattened cone which joins the medial end of the utricle at a right angle.* From the anteromedial part of the utricle a fine canal, named the *ductus utriculosaccularis*, is given off, and opens into the ductus endolymphaticus.

* J. K. Milne Dickie, *Journal of Laryngology, Rhinology and Otology*, 1920, 35, 76.

FIG. 1060.—The left membranous labyrinth of a fifth-month human embryo. $\times 10$.
Anterolateral aspect. (G. Retzius.)

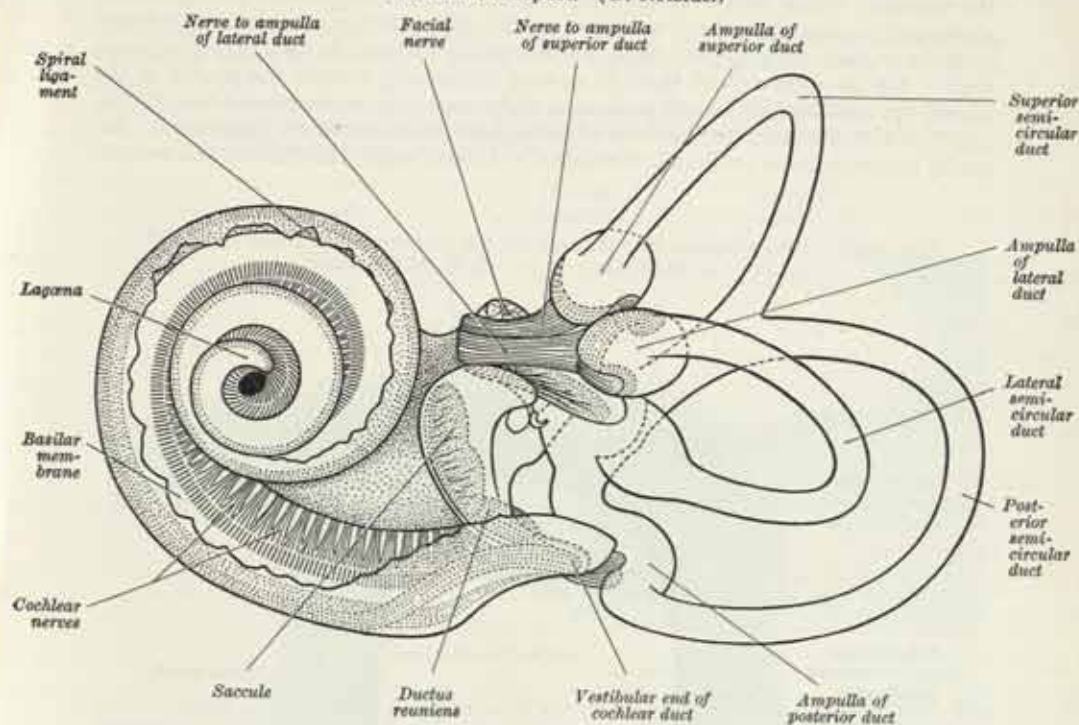
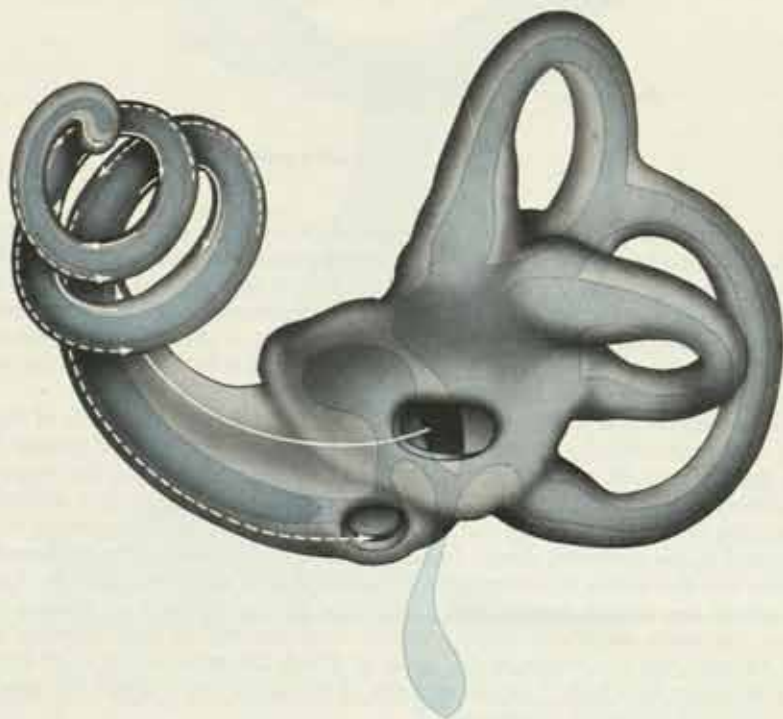


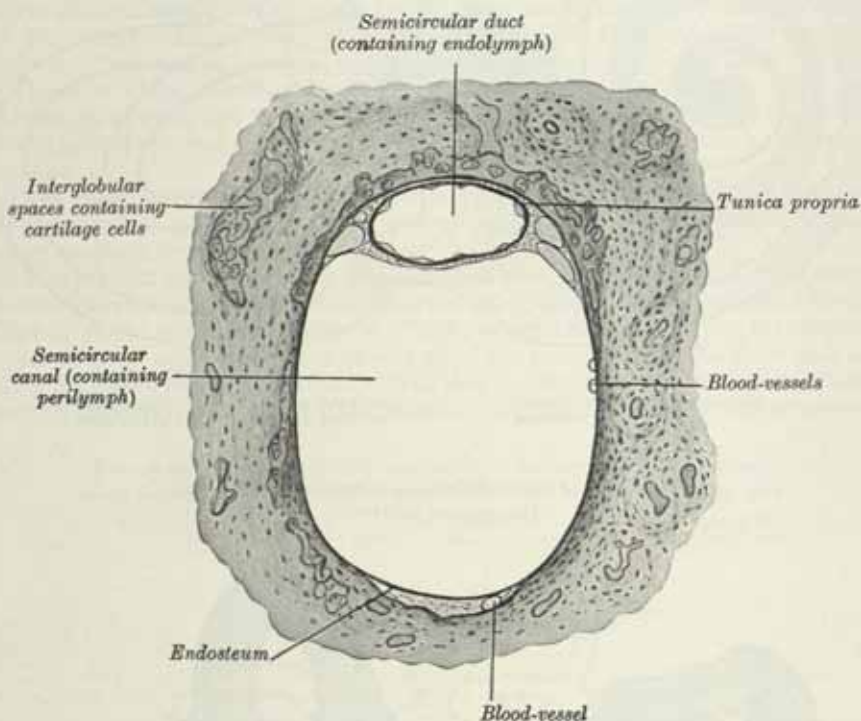
FIG. 1061.—Scheme of the membranous labyrinth (blue) projected on to the osseous labyrinth.



The arrows commence at the fenestra vestibuli and continue up the scala vestibuli to the helicotrema, and then pass down the scala tympani to the fenestra cochleae.

The **saccul** lies in the spherical recess near the opening of the scala vestibuli of the cochlea. When seen from the front it presents a nearly globular form, but it is prolonged backwards in the form of a cone, the upper surface of which is in contact with the under surface of the utricle, and the utricle and saccul have here a common wall.* On its anterior wall there is an oval thickening, termed the *macula of the saccul* (p. 1288) which lies in a plane at right angles to the macula of the utricle, and to which the saccular filaments of the eighth cranial nerve are distributed. Its cavity communicates indirectly through a Y-shaped tube with that of the utricle.

FIG. 1062.—A transverse section through the left posterior semicircular canal and duct of an adult man. $\times 51$. (J. K. Milne Dickie.)



From its posterior part the *ductus endolymphaticus* is given off, and it is joined by the *ductus utriculosaccularis*; the *ductus endolymphaticus* passes inwards and then downwards along the aqueduct of the vestibule and ends in a blind pouch (*sacculus endolymphaticus*) under the dura mater on the posterior surface of the petrous portion of the temporal bone. From the lower part of the saccul a short tube, named the *ductus reuniens*, passes downwards and gradually widens into the vestibular or basal end of the duct of the cochlea (fig. 1059).

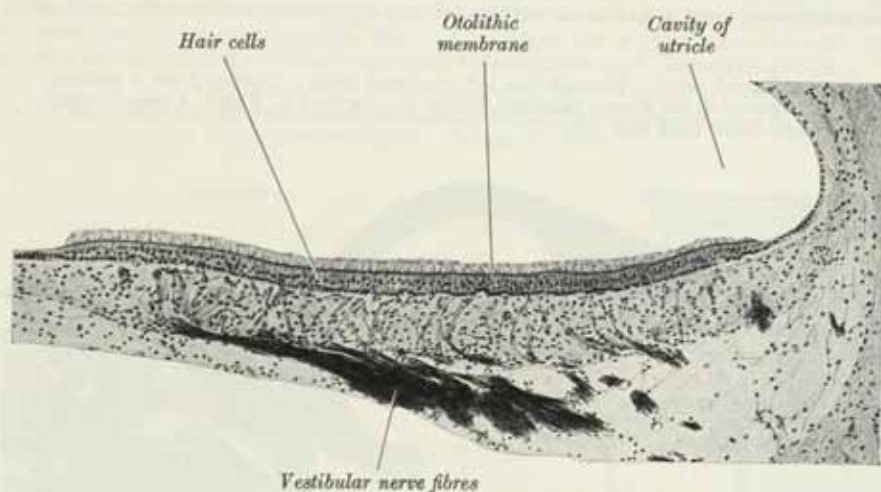
The **semicircular ducts** (figs. 1059 to 1062) are about one-fourth of the diameter of the semicircular canals, but are similar to them in shape and general form. Each has an ampulla at one end, viz.: the end which lies within the ampulla of the corresponding bony canal. The semicircular ducts open by five orifices into the utricle, one opening being common to the medial end of the superior, and the upper end of the posterior, duct. In each of the ampullæ the wall is thickened, and projects into the cavity as a transverse elevation shaped somewhat like the figure 8, and named the *septum transversum*; the most prominent part of this septum is termed the *crista ampullaris* which projects from the wall of each ampulla that is most distant from the centre of the circle of which the semicircular duct forms an arc, a situation in which "any movement of the endolymph would be caught by the crista to the greatest advantage".*

* J. K. Milne Dickie, *J. Laryngol. Rhinol. Otol.*, 1920, 35, 76.

The utricle, saccule and semicircular ducts are held in position by fibrous bands which stretch across the perilymphatic space to the bony walls.

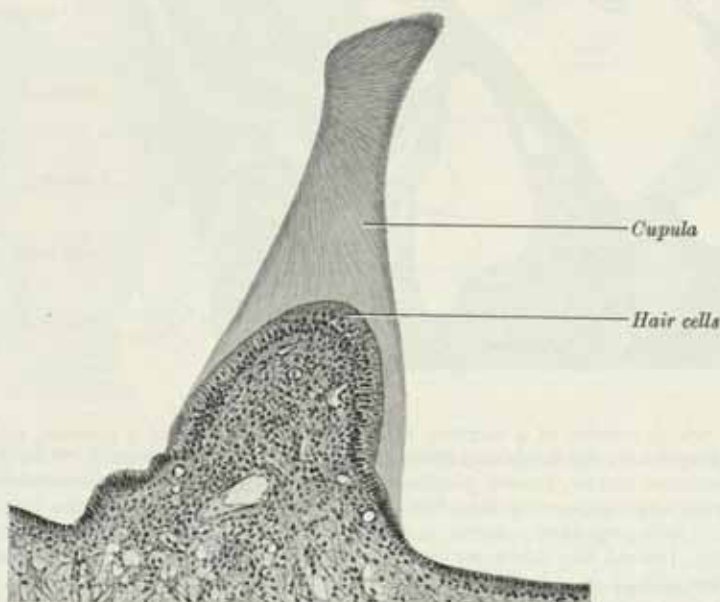
Structure (fig. 1062).—The walls of the utricle, saccule and semicircular ducts consist of three layers. The outer layer is composed of fibrous tissue containing

FIG. 1063A.—Section of the macula of the utricle of the cat. Stained Weigert Pal and iron haematoxylin ($\times \delta 112$). (Drawn from a section prepared at the Ferrens Institute, kindly lent by Prof. E. W. Walls.)



blood-vessels and blending in places with the endosteum of the bony labyrinth. The *middle* layer (tunica propria) is more transparent and presents on its internal surface, especially in the semicircular ducts, a number of papilliform projections. The *inner*

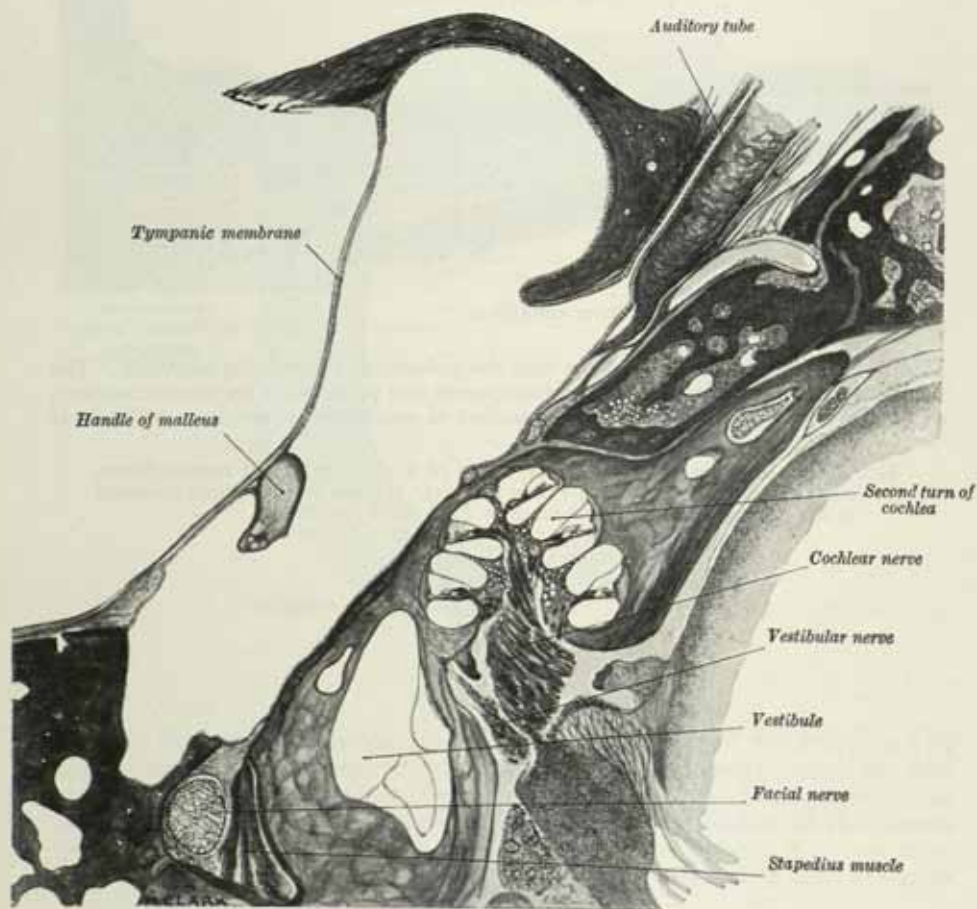
FIG. 1063B.—Section of an ampullary crest of a six months old human foetus. Stained with haematoxylin and eosin ($\times \delta 75$). (Drawn from a section prepared at the Ferrens Institute, kindly lent by Prof. E. W. Walls.)



layer consists in general of a single layer of epithelial cells, which are cubical or polygonal in shape, resting on a basement membrane; they undergo a specialised arrangement in the ampullary crests of the semicircular ducts and in the maculae of the utricle and saccule (figs. 1063A and 1063B). In these special sites, also, the middle

coat is thickened. In the ampullary crests the epithelium consists of *supporting cells* and *hair cells*. The supporting cells are elongated, fusiform cells, their deep ends reaching the tunica propria and their free surfaces united to form a thin cuticle. The hair-cells are flask-shaped, their deep ends do not reach as far as the tunica propria and they lie between the superficial parts of the supporting cells. From the free end of each hair-cell a long tapering cilium projects into a thick, dome-shaped gelatinous mass called the *cupula*. The supporting and hair-cells of the maculae of the utricle and saccule are similar to those of the ampullary crests, but the gelatinous mass into which the cilia project is flatter and is termed the *otolithic membrane*, and moreover this gelatinous mass contains numerous minute crystalline bodies called otoliths or

FIG. 1064.—A section through the left temporal bone. (Drawn from a section, prepared at the Ferens Institute, kindly lent by Prof. J. Kirk.) Compare with figs. 1046, 1048 and 1065.



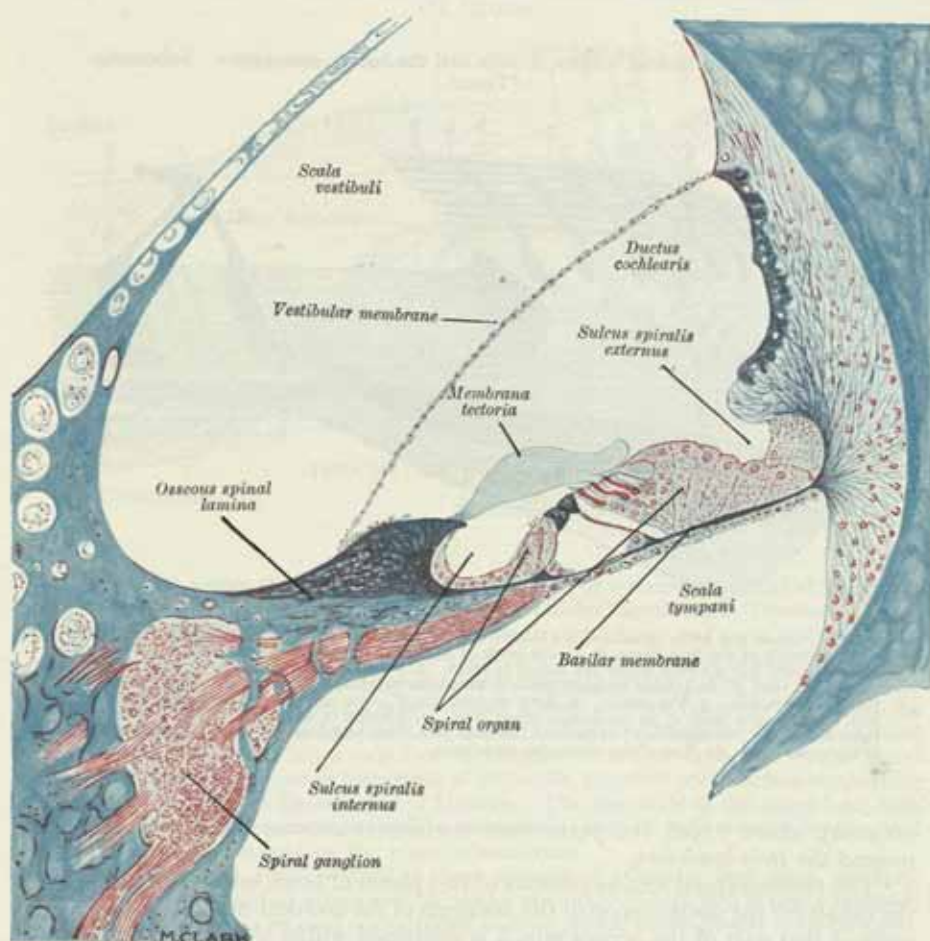
otoconia, which consist of a mixture of calcium carbonate and a protein, and which give the maculae in the fresh condition an opaque white appearance. The filaments of the vestibular nerve, having pierced the tunica propria, lose their myelin sheaths and their axis-cylinders split into fine fibrils which ramify between the hair cells of the maculae and ampullary crests.

A ridge, named the *crista quarta*, projects into the posterior end of the lateral semicircular duct; it is well developed in lower vertebrates and is present in most mammals, but is only rudimentary in man; nerve fibres have been traced into this crest.

The ampullary crests and the maculae of the utricle and saccule are the special end-organs concerned with equilibratory vestibular reflexes influencing firstly, the position of the eyes in relation to movements of the head through the connections of the vestibular nerves and their nuclei via the medial longitudinal bundle (p. 994) with

the nuclei of the third, fourth and sixth cranial nerves; and secondly, muscle tone through the vestibulo-spinal tracts (p. 941). Muscle tone is also influenced by the position of the head, and in this case the maculae of the utricle and saccule are the end-organs concerned in that the otoliths, under the influence of gravity, exert traction on the cilia of the hair-cells in varying positions of the head. The maculae are therefore referred to as organs of static balance (stato-tonic reflexes), whereas the ampullary crests are called organs of kinetic balance in that they are stimulated by movement of, or pressure changes in, the endolymph caused by movements of the head (stato-kinetic reflexes) producing deviation of the cupulae. The macula of the saccule, although it has the same histological structure as the macula of the utricle, is believed by some not to be concerned in vestibular reflexes but to be associated with the cochlea and concerned with the reception of slow vibrational (auditory) stimuli.

FIG. 1065.—A section through the second turn of the cochlea indicated in the previous figure. (Mallory's stain.)

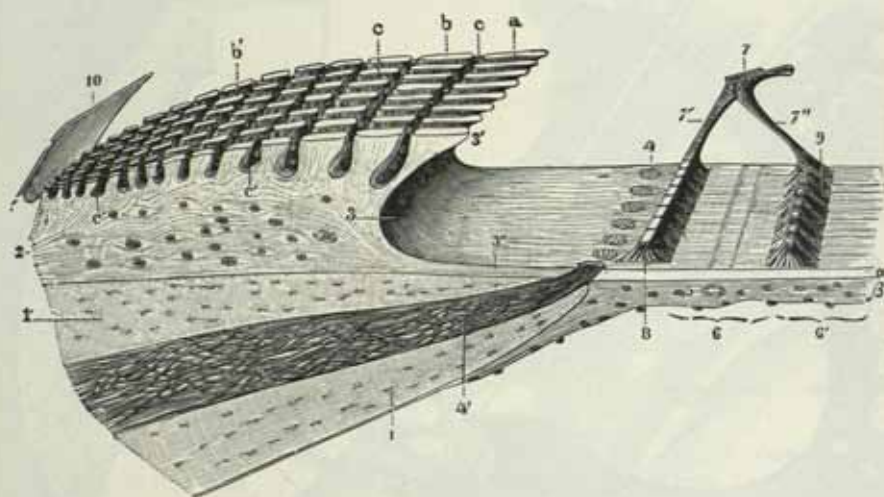


The **duct of the cochlea** consists of a spirally arranged tube within the bony canal of the cochlea and lying along its outer wall.

As already stated (p. 1283) the osseous spiral lamina extends only part of the distance between the modiolus and the outer wall of the cochlea, while the *basilar membrane* stretches from the free edge of the lamina to the outer wall of the cochlea, and completes the roof of the scala tympani. The endosteum of the outer wall of the cochlea is thickened to form the *spiral ligament of the cochlea*; it projects inwards and to it is attached the outer edge of the basilar membrane. A second and more delicate membrane, termed the *vestibular membrane*, extends from the thickened endosteum covering the osseous spiral lamina to the outer wall of the cochlea, where it is attached at some distance above the outer edge of the basilar

membrane. A canal is thus shut off between the scala tympani below and the scala vestibuli above; this is the *duct of the cochlea* (fig. 1065). It is triangular on transverse section, its roof being formed by the vestibular membrane, its outer wall by the endosteum lining the bony canal, and its floor by the basilar membrane and the outer part of the osseous spiral lamina. The upper extremity of the duct of the cochlea is closed, and is named the *lagæna*; it is attached to the cupola (p. 1282). The lower end turns medially, and narrows into the *ductus reuniens*, through which it communicates with the sacculæ (fig. 1059). The spiral organ is situated on the basilar membrane. The vestibular membrane is thin and homogeneous, and is covered on its two surfaces by a layer of flattened epithelium. The endosteum forming the outer wall of the duct of the cochlea is greatly thickened and altered in character to form the spiral ligament. It projects inwards, inferiorly, as a triangular prominence, termed the *crista basilaris*, to which the outer edge of the basilar membrane is fixed; immediately above this there is a concavity (the *sulcus spiralis*

FIG. 1066.—The limbus laminae spiralis and the basilar membrane. Schematic. (Testut.)



1, 1'. Upper and lower lamellae of the lamina spiralis ossea. 2, 2'. Limbus laminae spiralis, with 2, the auditory teeth and the cells which are lodged in them. 3, 3'. Sulcus spiralis internus, with 3', its labium vestibulare, and 3'', its labium tympanicum. 4, 4'. Foramina nervosa, giving passage to the nerves from the spiral ganglion. 5, 5'. Vasa spiralia. 6, 6'. Zona arcuata, and 6'', zona pectinata of the basilar membrane, with 6''', its hyaline layer. 7, 7'. Connective tissue layer. 8, 8'. Summit of the tunnel of Corti, with 8'', its inner rod, and 8''', its outer rod. 9, 9'. Bases of the inner rods, from which the cells are removed. 10, 10'. Bases of the outer rods. 11. Part of the vestibular membrane.

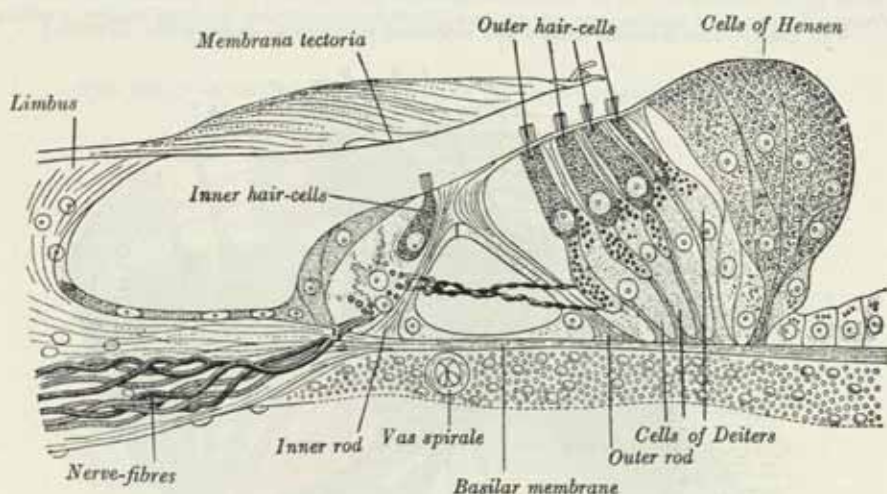
externus), above which the periosteum contains numerous blood-vessels, and is termed the *stria vascularis*.

The osseous spiral lamina consists of two plates of bone, and between these are the canals for the transmission of the filaments of the cochlear nerve. On the upper plate of that part of the lamina which is contained within the duct of the cochlea the periosteum is thickened to form the *limbus laminae spiralis* (fig. 1066); this ends externally in a concavity (the *sulcus spiralis internus*), which presents, on section, the form of the letter C; the upper part formed by the overhanging edge of the limbus is named the *vestibular lip*; the lower part, prolonged and tapering, is called the *tympanic lip*, and is perforated by numerous foramina for the passage of the branches of the cochlear nerve. The upper surface of the vestibular lip is intersected at right angles by a number of furrows, separated by numerous elevations; these present the appearance of teeth on the free surface and margin of the lip, and were named by Huschke the *auditory teeth* (fig. 1066). The limbus is covered by a layer of what appears to be squamous epithelium, but only the cells covering the teeth are flattened, those in the furrows being columnar, and occupying the intervals between the elevations. This epithelium is continuous on the one hand with that lining the

sulcus spiralis internus, and on the other with that covering the under surface of the vestibular membrane.

The basilar membrane.—The basilar membrane (figs. 1065, 1067) stretches from the tympanic lip of the osseous spiral lamina to the crista basilaris. Its inner part is thin, and is named the *zona arcuata*; it supports the spiral organ; the outer part is thicker and striated, and is termed the *zona pectinata*. The width of the basilar membrane gradually increases from 0.21 mm. in the basal turn to 0.36 mm. in the apical turn of the cochlea, and this increase is accompanied by a corresponding narrowing of the osseous spiral lamina, and a decrease in the thickness of the crista basilaris. The under surface of the membrane is covered by a layer of vascular connective tissue; one of the vessels in this tissue is somewhat larger than the rest, and is named the *vas spirale*; it lies below Corti's tunnel.

FIG. 1067.—A transverse section through the spiral organ. Magnified.
(G. Retzius.)



The **spiral organ** (figs. 1065, 1067) is composed of a series of epithelial structures placed upon the *zona arcuata* or inner part of the basilar membrane. The more central of these structures are two rows of rod-like bodies (the *inner and outer rods of Corti*). The bases or *foot-plates* of the rods are expanded, and rest on the basilar membrane, those of the inner row at some distance from those of the outer; the two rows incline towards each other and, coming into contact above, enclose between them and the basilar membrane the *tunnel of Corti* (fig. 1068), which is triangular in cross section. On the medial side of the inner rods there is a single row of hair-cells, and on the lateral side of the outer rods, three or four rows of hair-cells, together with certain supporting cells termed the cells of Deiters and of Hensen. The free ends of the outer hair-cells occupy a series of apertures in a net-like membrane, termed the *reticular lamina*, and the entire organ is covered by the *tectorial membrane*.

Rods of Corti (fig. 1068).—Each of these consists of a base or foot-plate, an elongated part or body, and an upper end or head; the body of each rod is finely striated, but in the head there is an oval non-striated portion which stains deeply with carmine. Nucleated cells, which partly envelop the rods and extend on to the floor of Corti's tunnel, occupy the angles between the rods and the basilar membrane; these may be looked upon as the undifferentiated parts of the cells from which the rods have been formed.

The *inner rods* number nearly 6000, and their bases rest on the basilar membrane close to the tympanic lip of the sulcus spiralis internus. The shaft or body of each is sinuously curved and forms an angle of about 60° with the basilar membrane. The head resembles the proximal end of the ulna, and presents a deep concavity which accommodates a convexity on the head of the outer rod. The head-plate, or portion overhanging the concavity, overlaps the head-plate of the outer rod.

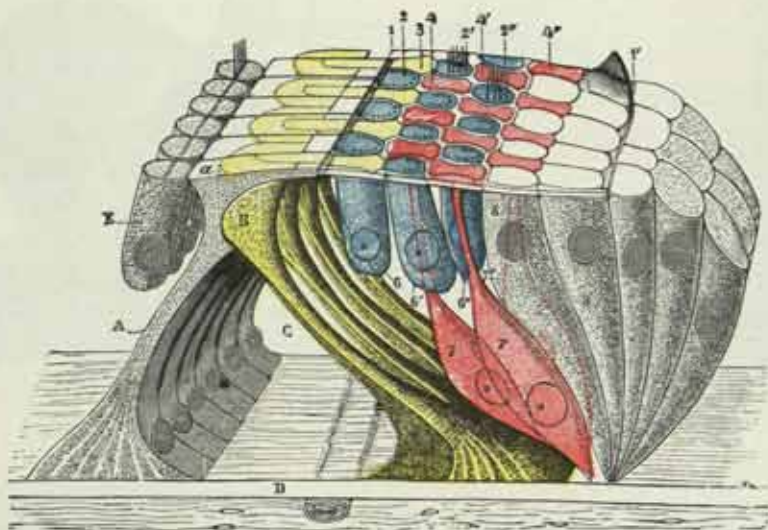
The *outer rods*, nearly 4000 in number, are longer and more obliquely set than the inner, forming with the basilar membrane an angle of about 40° . Their heads are convex internally; they fit into the concavities on the heads of the inner rods, and are continued outwards as thin flattened plates, termed *phalangeal processes*,

which unite with the phalangeal processes of Deiters' cells to form the reticular membrane.

The distances between the bases of the inner and outer rods increase from the base to the apex of the cochlea, while the angles between the rods and the basilar membrane diminish.

Hair-cells.—The hair-cells are short columnar cells; their free ends are on a level with the heads of the rods of Corti, and each is surmounted by about twenty hair-like processes arranged in the form of a crescent with its concavity directed inwards. The deep ends of the cells reach about halfway along the rods of Corti, and each contains a large nucleus; the terminal filaments of the cochlear nerve are in contact with the deep ends of the hair-cells. The *inner* hair-cells, about 3500 in number, are arranged in a single row on the inner (axial) side of the inner rods, and, their diameters being greater than those of the rods, each is supported by more than one rod. The free ends of the inner hair-cells are encircled by a cuticular membrane which is fixed to the heads of the inner rods. Adjoining the inner hair-cells there are one or two rows of columnar supporting cells, which, in turn, are continuous with the cubical cells lining the sulcus

FIG. 1068.—The reticular lamina and subjacent structures. Schematic. (Testut.)



A. Inner rod of Corti, with *a*, its head. B. Outer rod (in yellow). C. Tunnel of Corti. D. Basilar membrane. E. Inner hair-cells. 1, 1'. Internal and external borders of the reticular lamina. 2, 2', 2''. The three rows of circular holes (in blue). 3. First row of phalanges (in yellow). 4, 4', 4''. Second, third, and fourth rows of phalanges (in red). 5, 5', 5''. The three rows of outer hair-cells (in blue). 6, 6', 6''. Cells of Deiters. 7, 7', 7''. Cells of Hensen and Claudius.

spiralis internus. The *outer* hair-cells number about 12,000 and are nearly twice as long as the inner. In the basal coil of the cochlea they are arranged in three regular rows; in the apical coil, in four somewhat irregular rows.

Rows of supporting cells, called the *cells of Deiters* (fig. 1067), are placed between the rows of the outer hair-cells; their expanded bases are planted on the basilar membrane, while the opposite end of each presents a clubbed extremity or *phalangeal process*. Immediately to the outer side of Deiters' cells there are five or six rows of columnar cells, named the *supporting cells of Hensen* (fig. 1067). Near the lagæna these cells contain fat globules which decrease in number and size as the duct of the cochlea is traced towards the basal coil. It has been suggested* that these globules provide a graduated loading mechanism, which tunes the region of the lagæna to low tones.

The *reticular lamina* (fig. 1068) is a delicate framework perforated by circular holes which are occupied by the free ends of the outer hair-cells. It extends from the heads of the outer rods of Corti to the external row of the outer hair-cells, and is formed by several rows of minute fiddle-shaped cuticular structures, called *phalanges*, between which are circular apertures containing the free ends of the hair-cells. The innermost row of phalanges consists of the phalangeal processes of the outer rods of Corti; the outer rows are formed by the modified free ends of Deiters' cells.

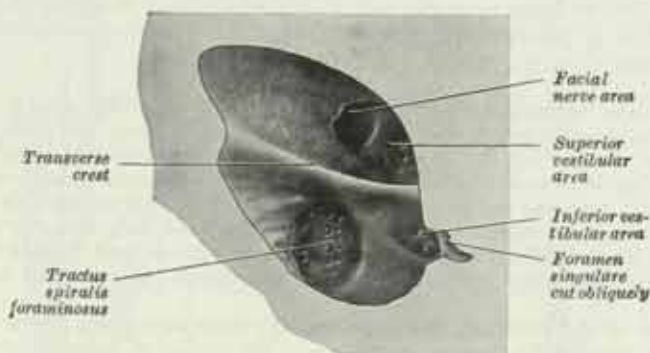
The *membrana tectoria* (fig. 1067) overlies the sulcus spiralis internus and the spiral

* C. S. Hallpike, *J. Physiol.*, 73, 1931.

organ of Corti. It consists of delicate fibres embedded in a jelly-like matrix. It is wider and thicker in the apical than in the basal part of the cochlea. Its inner part is thin and is attached to the vestibular lip of the limbus laminae spiralis, the attachment reaching as far as the vestibular membrane. The outer part is thick and padlike, the thickness being greatest over, or slightly to the inner side of, the upper ends of the rods of Corti. Retzius described the outer edge as being attached to the outer row of Deiters' cells, while others maintain that it forms a ragged or frayed margin. Hardesty,* who has examined the membrane in the pig, states that this edge is free and bluntly rounded, but finely and irregularly scalloped. The hairs of the hair-cells project into the under surface of the membrane, and on this surface opposite the interval between the inner and outer rows of hair-cells there is a band, named *Hensen's stripe*.

Hardesty has shown that the *membrana tectoria* "consists of multitudes of delicate fibrils imbedded in a transparent matrix of a soft, collagenous, semi-solid character with marked adhesiveness." The prevailing course of the fibres is obliquely transverse, slanting from the vestibular lip towards the apex of the cochlea. The fibres pass in curves from the vestibular lip and upper surface of the membrane to its under surface, where by their interlacement they produce the appearance known as *Hensen's*

FIG. 1069.—A view of the lateral end of the right internal acoustic meatus.



stripe. He also described a thin, exceedingly delicate *accessory tectorial membrane*, lying along the under surface of the outer zone of the main membrane, and lightly attached to the latter by its outer edge.

Mechanism of hearing.—Sound waves set the tympanic membrane in vibration, which is transmitted by the auditory ossicles (p. 1278) to the fenestra vestibuli and thence to the perilymph. Vibrations in the latter cause movements of the basilar membrane with consequent stimulation of the hair-cells and the nerve endings of the cochlear nerve. There is tonal localisation in the spiral organ of the cochlea, the basal coil being affected by high-pitched notes and the apical coil by low notes. In this connection it is to be noted that the basilar membrane is narrowest in the basal coil and progressively widens towards the apical coil (p. 1291), and that the spiral ligament of the cochlea is more massive in the basal coil, suggesting that this part of the basilar membrane is more tense than the part in the apical coil. Little understood hydrodynamic factors in the endolymph are also thought to play a part in the mechanism whereby different frequencies of vibration activate different parts of the basilar membrane. Different parts of the spiral organ are innervated by different fibres of the cochlear nerve, and vibrations of a segment of the organ stimulate local nerve endings so that impulses will eventually reach a localised region of the auditory area of the cerebral cortex, where the pitch of the sound is appreciated.

The **eighth cranial nerve** (*stato-acoustic nerve*) divides near the bottom of the internal acoustic meatus into an anterior or cochlear, and a posterior or vestibular portion. The deep connexions and proximal parts of these nerves are described on pp. 1123 to 1126.

The *vestibular nerve* supplies the utricle, the saccule and the ampullae of the semicircular ducts. The *vestibular ganglion*, from the bipolar nerve-cells of which the fibres of the nerve take origin, is situated on the trunk of the nerve within the internal acoustic meatus. On the distal side of the ganglion the nerve splits into a

* Irving Hardesty, *Amer. J. Anat.*, 8, 1908.

superior, an inferior and a posterior branch.* The filaments of the *superior branch* are transmitted through the foramina in the superior vestibular area, and end in the macula of the utricle and in the ampullary crests of the superior and lateral semicircular ducts; those of the *inferior branch* traverse the foramina in the inferior vestibular area, and end in the macula of the saccule. The *posterior branch* runs through the foramen singulare at the postero-inferior part of the bottom of the meatus (fig. 1069) and divides into filaments for the supply of the ampullary crest of the posterior semicircular duct.

The *cochlear nerve*, the nerve of hearing, divides into numerous filaments at the base of the modiolus; those for the basal and middle coils pass through the foramina in the tractus spiralis foraminosus, those for the apical coil through the central canal, and the nerves bend outwards and pass between the lamellæ of the osseous spiral lamina. The *spiral ganglion* (fig. 1065), consisting of bipolar nerve-cells from which the fibres of the nerve take origin, occupies the spiral canal of the modiolus. Reaching the outer edge of the osseous spiral lamina, the nerve-fibres pass through the foramina in the tympanic lip; some end by arborising around the deep ends of the inner hair-cells, while others pass between the rods of Corti and across the tunnel of Corti, and end in a similar manner in relation to the outer hair-cells. The hair-cells in the basal and middle coils are more richly supplied with nerves than those in the apical coil. The cochlear nerve gives off a vestibular branch to supply the vestibular end of the duct of the cochlea; the filaments of this branch traverse the foramina in the cochlear recess (p. 1281).

Vessels.—The *arteries of the labyrinth* are (1) the labyrinthine artery, which may arise from the basilar artery, but is more often derived from the anterior inferior cerebellar artery, and (2) the stylomastoid branch of the posterior auricular artery. The internal auditory artery divides at the bottom of the internal acoustic meatus into two branches: cochlear and vestibular. The cochlear branch subdivides into twelve or fourteen twigs, which traverse the canals in the modiolus, and are distributed, in the form of a capillary network, in the lamina spiralis and basilar membrane. The vestibular branches are distributed to the utricle, saccule and semicircular ducts.

The *veins* of the vestibule and semicircular canals accompany the arteries, and, receiving the veins of the cochlea at the base of the modiolus, unite to form the labyrinthine vein, which ends in the posterior part of the superior petrosal sinus or in the transverse sinus. A small vein, from the basal turn of the cochlea, traverses the aqueduct of the cochlea and joins the internal jugular vein.

THE SKIN

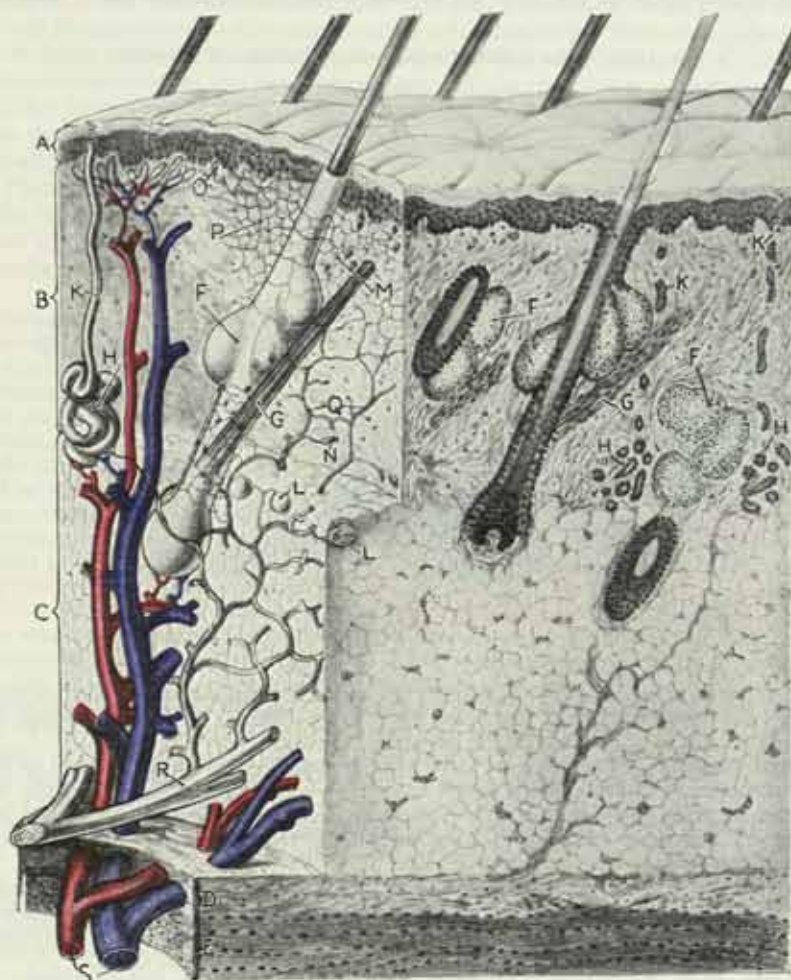
The *skin* (fig. 1070) covers the body and protects the deeper tissues. It contains the peripheral endings of many of the sensory nerves, plays an important part in the regulation of the body temperature, and possesses limited excretory and absorbing powers. It consists principally of a layer of vascular connective tissue, named the *corium*, and an external covering of epithelium, termed the *epidermis*. On the surface of the corium there are sensitive and vascular *papillæ*; and within, or beneath it, there are certain organs with special functions: namely, the *sweat* and *sebaceous glands*, and the *hair-follicles*.

The *epidermis* is non-vascular, and consists of stratified epithelium (fig. 1071). It varies in thickness in different parts. In some situations, as in the palms of the hands and soles of the feet, it is thick, hard, and horny in texture. This may be in a measure due to the fact that these parts are exposed to intermittent pressure, but that this is not the only cause is indicated by the fact that the condition exists to a very considerable extent at birth. The more superficial layers of cells form the *horny zone* (*stratum corneum*), which may be separated by maceration from a deeper stratum, termed the *germinative zone* that consists of several layers of variously shaped cells. The free surface of the epidermis is marked by a network of linear furrows of variable size, which divide the surface into a number of polygonal or lozenge-shaped areas. These furrows are conspicuous opposite the flexures of the joints, and correspond with the folds in the corium produced by the joint-movements. In other

* The nerve sometimes splits on the proximal side of the ganglion, which is then divided into three parts, one on each branch of the nerve. When this occurs the ganglion of the posterior division is placed in the foramen singulare.

situations, as upon the back of the hand, they are faint, and intersect one another at various angles. Upon the palmar surfaces of the hands and fingers, and upon the soles of the feet, these lines are fine but very distinct, and are disposed in more or less parallel curves; they depend upon the large size and peculiar arrangement of the papillæ upon which the epidermis is placed. In each individual the lines on the tips of the fingers and thumbs form distinct patterns unlike those of any other person.

FIG. 1070.—A scheme showing the structure of the skin. Magnified. Diagrammatic. Based partly on the scheme shown in fig. 803.



A. Epidermis. B. Dermis. C. Subcutaneous fat. D. Deep fascia. E. Muscle. F. Sebaceous glands in association with a hair follicle. G. Arrector pili muscle. H. Sweat gland. K. Duct of sweat gland. L. Bulbous corpuscle. M. Lamellated end-bulb. N. Pressure corpuscle. O. Oval corpuscle in a papilla. P. Superficial nerve plexus. Q. Deep nerve plexus. R. Cutaneous nerve. S. Cutaneous vessels.

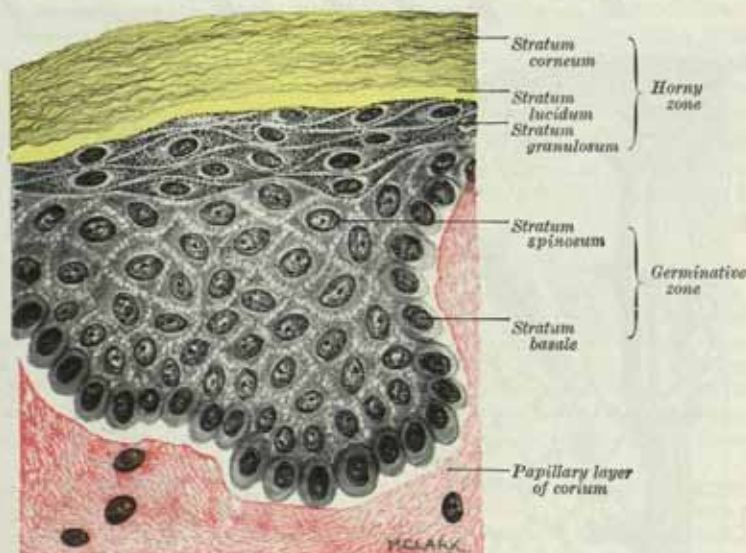
The method of identification of an individual by means of 'finger-prints' is based on this fact, impressions of these lines being made on paper covered with soot, or on white paper after first covering the fingers with ink. The deep surface of the epidermis is accurately moulded upon the papillary layer of the corium, the papillæ being covered by a basement-membrane; as a result, when the epidermis is removed by maceration, its under surface presents a number of pits or depressions corresponding with the papillæ, and ridges corresponding with the intervals between them. The papillary form of the corium prevents the epithelium from being stripped off the surface of the skin by shearing stresses.

Structure.—The epidermis consists of stratified squamous epithelium, which is arranged in two zones, viz. : the germinative zone and the horny zone. The germinative zone, which is the deeper, consists of basal-cell and prickle-cell layers ; the horny zone consists of clear, granular and horny layers.

Germinative zone : (1) The *basal-cell layer* (*stratum basale*) consists of a layer of columnar cells with oblong nuclei. The cells are placed perpendicularly on a basement-membrane, to which they are attached by denticulated extremities.

(2) The *prickle-cell layer* (*stratum spinosum*) is composed of several layers of spherical or polyhedral cells which are joined to one another by fine protoplasmic bridges. When the cells are isolated these bridges are broken and the surfaces of the cells are beset with numerous short thorn-like processes, which give the cells a characteristic appearance and have led to their being named *prickle-cells*. The cells

FIG. 1071.—The stratified squamous epithelium of the skin.



contain numerous fine fibrils (tonofibrils) which are continuous with those of neighbouring cells by means of the protoplasmic bridges. Some, however, maintain that the fibrils do not exist as such in the living unfixed cells.

Horny zone : (1) The *granular layer* (*stratum granulosum*) comprises two or three layers of fusiform cells which contain numerous granules that stain readily with haematoxylin and consist of a substance (keratohyalin) which is believed to be a stage in the transformation of the protoplasmic cells of the stratum spinosum into the keratin of the cells of the stratum corneum.

(2) The *clear layer* (*stratum lucidum*) appears in section as a homogeneous or dimly striated layer, composed of closely packed cells in which traces of flattened nuclei may be found, and in which the keratohyalin has been changed into a substance named eleidin. It is best seen in regions where the horny zone is thick.

(3) The *horny layer* (*stratum corneum*) consists of several layers of horny, epithelial cells, in which no nuclei are discernible and their protoplasm has been converted into a material known as *keratin*.

Pigmentation of the skin.—Even in white races most parts of the skin contain brown (melanin) pigment granules in the deepest layers of the germinative zone of the epidermis ; in dark races they are more abundant and extend through the whole zone. The colour of the skin of different races is the resultant of at least five pigments, namely melanin, melanoid (a substance allied to melanin and diffused throughout the epidermis), carotene (in the stratum corneum and the fat of the corium and subcutaneous tissue), oxyhaemoglobin and reduced haemoglobin (in the blood vessels of the corium and subcutaneous tissue). Complete absence of skin pigment in an individual results in the condition called albinism ; this is a recessive Mendelian character and may occur sporadically in any race. The origin of melanin is uncertain. Among the epidermal cells of the deeper layers of the germinative zone there are elaborately branched cells, termed *dendritic cells* (or

epidermal melanoblasts), the slender branches of which spread in the intercellular spaces and each ends in a flattened expansion which is applied to the surface of an epidermal cell.* A colourless chromogen, the nature of which is uncertain though some believe that its precursor is the aminoacid tyrosine, is brought by the bloodstream to the cells, and is there converted by a ferment (oxidase) into melanin. If sections of skin are treated with dioxyphenylalanin (which is used experimentally in this case as a chromogen), those cells which contain oxidase convert it into melanin. This is known as the 'Dopa' reaction (from the initials of the parts of the word di-oxy-phenyl-alanin), and demonstrates that it is only the dendritic cells that manufacture melanin. The melanin granules thus formed stream along the branches of the dendritic cells to their terminal expansions, from which they are actively phagocytosed by the neighbouring epidermal cells. Branched cells containing melanin granules are occasionally found in the superficial part of the corium (dermal melanoblasts) and connective tissue cells in the corium may ingest melanin granules from the dendritic cells. The origin of the dendritic cells is uncertain, some maintaining that they are modified epidermal cells, and others that they are derived and migrate from the neural crests.

The **corium** is tough, flexible and highly elastic. It is very thick in the palms of the hands and soles of the feet; thicker on the posterior than on the anterior aspect of the body, and on the lateral than on the medial sides of the limbs. It is exceedingly thin and delicate in the eyelids, scrotum, and penis.

Structure.—It consists of felted connective tissue, with a varying number of elastic fibres and numerous blood-vessels, lymphatic vessels and nerves. The connective tissue is arranged in two layers: a deeper or *reticular*, and a superficial or *papillary*. Unstriated muscular fibres are found in the superficial layers of the corium wherever hairs are present; they are also present in the subcutaneous areolar tissue of the scrotum, penis, labia majora and nipples. In the nipples the fibres are disposed in bands, closely reticulated and arranged in superimposed laminae.

The *reticular layer* consists of strong interlacing bands, composed chiefly of white fibrous tissue, but containing some yellow elastic fibres, which vary in number in different parts; connective tissue cells are often to be found flattened against the bundles of white fibrous tissue. In the deeper part the fasciculi are coarse, and the large intervals left by their interlacement are occupied by adipose tissue and sweat glands. Below the reticular layer is the subcutaneous areolar tissue which, except in a few situations, contains fat. The connective tissue bands in the reticular layer lie for the main part in parallel bundles, so that if a conical object is stabbed through the skin and then withdrawn it leaves a linear wound since the fibres are forced apart without much rupture. The directions taken by the parallel bundles vary in different parts of the body and constitute what are termed the 'cleavage lines' of the skin. Surgical incisions made along the cleavage lines heal with minimal formation of scar tissue, whereas incisions across these lines, owing to retraction of the severed fibres, lead to the formation of a broad scar. In general, the cleavage lines are arranged longitudinally in the skin of the limbs and more or less horizontally in the trunk and neck. With increasing age the yellow elastic fibres atrophy and the skin loses much of its elasticity and becomes wrinkled. If the skin becomes much stretched (as by rapidly growing tumours, fat deposition or pregnancy) the fibres in the reticular layer may undergo partial rupture and scar formation result which may be visible on the surface as white streaks. These are commonly seen on the anterior abdominal wall after pregnancy and are known as *lineæ gravidarum*. In many regions the skin is separated from the deep fascia or other structures by loose areolar tissue and in these sites the skin is freely movable over the deeper structures. Elsewhere, however, the skin may be firmly anchored to structures like the periosteum over 'subcutaneous' parts of bones, or to the deep fascia in regions related to movements of underlying joints. In the latter case there may be permanent creases in the skin known as 'flexure lines'; they are particularly evident on the palm of the hand and flexor surfaces of the digits, where they are arranged in relation to the movements of the digits.

The *papillary layer* consists of numerous highly sensitive and vascular eminences, termed the *papillae*, which rise perpendicularly from its surface. The papillae are minute conical projections, having round or blunted extremities, which may be divided into two or more parts, and are received into corresponding pits on the under surface of the epidermis. On the general surface of the body, and especially in parts endowed with slight sensibility, they are few in number and exceedingly minute; but in some situations, as upon the palmar surfaces of the hands and fingers, and upon the plantar surfaces of the feet and toes, they are large, closely aggregated together, and

* R. E. Billingham, *J. Anat., Lond.*, 1948, **82**, 93; and 1949, **83**, 109.

arranged in parallel curved lines, forming the elevated ridges seen on the free surface of the epidermis. Each ridge contains two rows of papillae and between the rows the ducts of the sudoriferous glands pass outwards to open on the summits of the ridges. Each papilla consists of very small and closely interlacing bundles of finely fibrillated tissue, with a few elastic fibres; within this tissue there is a capillary loop, and in some papillae, especially in the palms of the hands and the fingers, there are oval corpuscles.

The *arteries* supplying the skin form a network in the subcutaneous tissue, and from this network branches are distributed to the sweat glands, the hair-follicles and the fat. Other branches unite in a plexus immediately beneath the corium, and from this plexus fine capillary vessels pass into the papillae. Arteriovenous anastomoses are present in the corium of certain regions of the skin; those in the skin of the palmar surfaces of the digits are known as 'glomera' (pp. 699-701).

The *lymph vessels* of the skin, according to Handley* are arranged so that the skin is divided into small areas (8-12 mm. in diameter), each drained by an independent vertical trunk into the lymphatic plexus on the deep fascia. Forbes† on the other hand, denied this and showed that there are three layers of plexus formation (superficial, intermediate and deep) in the corium, the deep plexus communicating with the plexus on the deep fascia by trunks running through the subcutaneous tissues in fibrous strands between the lobules of fat; he found very free anastomoses between the lymphatics in the corium and no evidence of independent drainage from localised areas of skin.

The arrangement, mode of termination and functional significance‡ of the endings of the *nerves in the skin* are described on pages 919-921.

The **appendages of the skin** are the nails, the hairs, and the sweat and sebaceous glands.

The **nails** (fig. 1072) are flattened, elastic structures of a horny texture, placed upon the distal parts of the dorsal surfaces of the fingers and toes. The proximal part of the nail, called the *root*, is implanted into a groove in the skin; the exposed part is the *body* of the nail; the distal end forms the *free border*, and a little proximal to it the skin is attached to the under surface of the nail forming the *hyponychium*. The root of the nail is overlapped by a fold of skin, the *nail fold*, the stratum corneum of which is prolonged distally as a thin cuticular fold, the *eponychium*, to cover completely or partially the white opaque crescentic part of the nail called the *lunule*. The greater part of each collateral border of the nail is overlapped by a fold of skin, termed the *nail wall*. The nail itself is a greatly thickened stratum lucidum of the skin, and beneath it lies the germinative zone which, together with the subjacent corium, forms the *nail-bed*. Under the greater part of the nail the corium is thick and raised into a series of longitudinal ridges which are very vascular, and this accounts for the pink colour seen through the translucent nail. Near the root of the nail, however, the ridges are smaller, irregularly arranged and less vascular; moreover the tissue of the nail is here more opaque, hence this part of the nail is whiter and constitutes the *lunule*. The lunule is usually visible in the thumb nail, but in the other digits it becomes progressively more covered by the nail fold towards the little finger, in which it is generally hidden altogether. The germinative zone of the nail-bed consists functionally of two parts. The part beneath the root of the nail and the lunule (*germinal matrix*) is thicker and actively proliferative, and is concerned with the growth of the nail, the epidermal cells being gradually converted into the nail substance. On the other hand, the part beneath the rest of the nail (*sterile matrix*) is thinner and is not concerned with nail growth but provides a surface over which the growing nail glides. All growth of the nail therefore takes place at its root; the nail increases in thickness from its root to the distal edge of the lunule and the remainder is of uniform thickness. If a nail be removed without severely damaging the germinal matrix, a new nail will grow from this region. Disturbances of growth of the nails may occur in acute illnesses or local trauma, and transverse grooves may develop on the surface which move gradually distally with growth of the nails. Minute air bubbles, giving rise to white flecks, may develop in the substance of the nail. On an average nails grow about 0.5 mm. a week; growth is quicker in summer than in winter, and finger nails

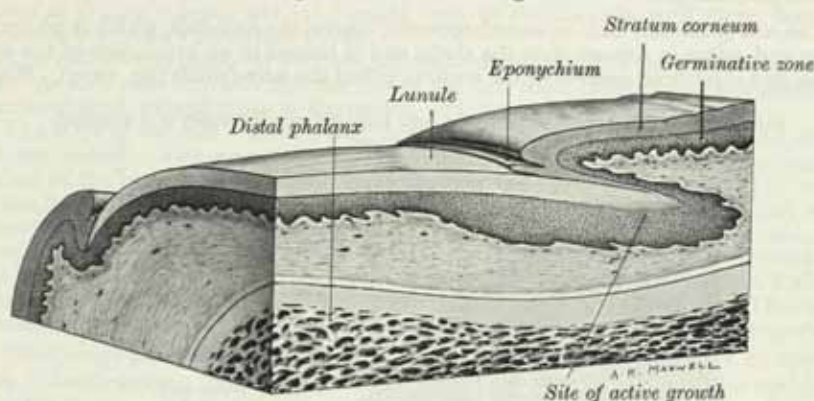
* W. S. Handley, "Cancer of the Breast", London. Murray, 1922.

† G. Forbes, *J. Anat.*, 72, 1938.

‡ For a detailed review of the nerve endings in the skin, see G. Weddell, E. Palmer and W. Pallie, "Nerve Endings in Mammalian Skin", *Biological Reviews*, 1955, 30, 159-195.

grow about 4 times as fast as toe nails. In the hand, nail growth is most rapid in the longest digit (the middle finger), slowest in the little finger and intermediate in the other digits. Nails act as a rigid background for support of the digital pads of the terminal phalanges, and thus may function in the tactile mechanism. From the

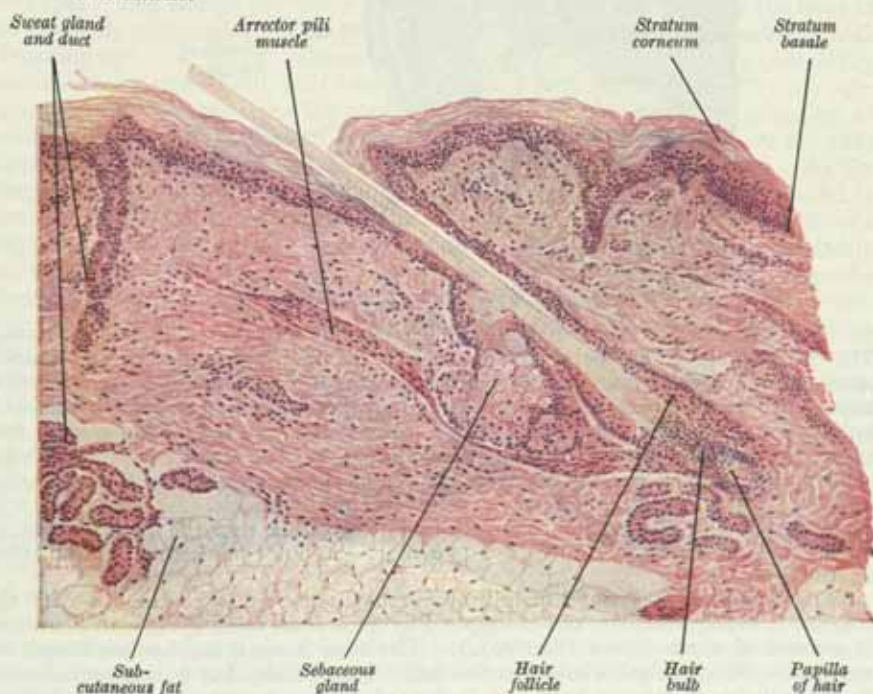
FIG. 1072.—A longitudinal section through the root of a nail.



evolutionary point of view, nails are derived from the more elaborately structured claws which characterise lower animals.

The **hairs** are found on nearly every part of the surface of the body, but are absent from the palms of the hands, the soles of the feet, the dorsal surfaces of the distal phalanges, the umbilicus, the glans penis, the inner surface of the prepuce,

FIG. 1073.—A section through the skin, showing the epidermis and corium, a hair in its follicle, the Arrector pili muscle, and sebaceous glands opening into the hair-follicle.



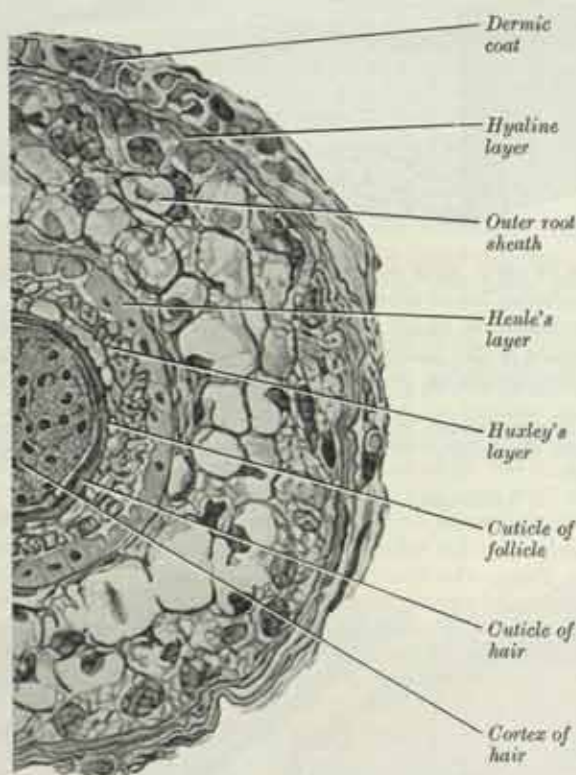
the inner surfaces of the labia majora and the labia minora. They vary much in length, thickness, and colour in different parts of the body and in different races of mankind. In some parts, as in the skin of the eyelids, they are so short as not to project beyond the follicles containing them; in others, as upon the scalp, they are of considerable length; the eyelashes, the hairs of the pubic region, and the

whiskers and beard are remarkable for their thickness. Straight hairs are stronger than curly hairs and present on transverse section a cylindrical or oval outline: curly hairs, on the other hand, are flat. Some maintain that the form of the hair does not correspond with its shape in cross section.

A hair consists of a *root*, the part implanted in the skin; and a *shaft* [*scapus*], the portion projecting from the surface.

The *root of the hair* ends in an enlargement, named the *hair-bulb*, which is whiter in colour and softer in texture than the shaft, and is lodged in an involution of the epidermis and superficial portion of the corium, called the *hair-follicle* (fig. 1073). When

FIG. 1074.—Transverse section of a hair follicle from the scalp of a newborn infant. $\times 600$.



the hair is of considerable length the follicle extends into the subcutaneous tissue. The hair-follicle commences on the surface of the skin with a funnel-shaped opening, and passes inwards in an oblique or curved direction—the latter in curly hairs—to become dilated at its deep extremity, where it corresponds with the hair-bulb. The ducts of one or more sebaceous glands open into the follicle near its free extremity. At the bottom of each hair-follicle there is a small conical, vascular eminence or papilla, similar in every respect to those found upon the surface of the skin; it is continuous with the dermic layer of the follicle, and is supplied with nerve-fibrils. It is from the capillaries in the papilla that the hair derives its nutrition. The hair-follicle consists of two coats—an outer or dermic, and an inner or epidermic (fig. 1073).

The *outer coat* is formed mainly of fibrous tissue; it is continuous with the corium, is highly vascular, and is supplied by numerous, minute, nervous filaments. It consists of three layers (fig. 1074). The most internal is a hyaline basement-membrane, which is well marked in the larger hair-follicles but is not very distinct in the follicles of minute hairs; it is limited to the deeper part of the follicle. Outside this there is a compact layer of fibres and spindle-shaped cells, arranged circularly around the follicle; this layer extends from the bottom of the follicle to the openings of the ducts of the sebaceous glands. Externally there is a thick layer of connective tissue, arranged in longitudinal bundles, forming a more open texture and corresponding with the reticular part of the corium; this contains the blood-vessels and nerves.

The *inner coat* is closely adherent to the root of the hair, and consists of two strata, named respectively the *outer* and *inner root-sheaths*; the outer root-sheath corresponds with the stratum spinosum of the epidermis, and resembles it in the rounded form and soft character of its cells; at the bottom of the hair-follicle these cells become continuous with those of the root of the hair. The inner root-sheath consists of: (1) a delicate cuticle next the hair, composed of a single layer of imbricated scales with atrophied nuclei; (2) one or two layers of horny, flattened nucleated cells, known as Huxley's layer; and (3) a single layer of cubical cells with clear, flattened nuclei, called *Henle's layer* (fig. 1074).

The *hair-bulb* is moulded over the papilla and composed of polyhedral, epithelial cells. As they pass upwards into the root of the hair these cells become elongated and spindle-shaped, except those in the centre, which remain polyhedral.

The *shaft of the hair* consists, from within outwards, of the medulla, the cortex and the cuticle. The *medulla* is usually absent from the fine hairs covering the surface of the body, and commonly from those of the head. When viewed by transmitted light it appears deeper in colour and more opaque than the cortex, but when viewed by reflected light it is white. It is composed of rows of polyhedral cells, with air-spaces between, and sometimes within, the cells. The *cortex* constitutes the chief part of the shaft; its cells are elongated and are united to form flattened, fusiform fibres, which contain pigment-granules in dark hair, and air in white hair. The *cuticle* consists of a single layer of flat scales which overlap one another from below upwards.

Over most parts of the body the hairs are fine and downy and give an appearance of hairlessness. Almost the entire skin of the human at about the middle of foetal life is covered by a fine hair, called *lanugo* (primary hairs), and in fact the hairs on the back at this time are more numerous (per square centimetre) than in the gorilla or chimpanzee of corresponding foetal age. The lanugo hairs are mostly shed by birth and are replaced by fine hairs, termed *vellus* (secondary hairs), in the early months of postnatal life. These are retained in most regions but are replaced by the hairs (terminal hairs) of the scalp and eyebrows; also by the axillary and pubic hairs, and those on the face and front of the chest in the male, which appear at puberty, their development and growth being under hormonal control. In the adult the scalp hairs are more numerous (per square centimetre) than in the anthropoid apes. The lanugo and vellus hairs have no medulla. In the male the hairs in the vestibule of the nose and in the external auditory meatus grow markedly with advancing age. In 'furry' mammals hair functions in the temperature controlling mechanism by minimising heat loss; this function in man is served by the subcutaneous fat, and the hairs are concerned largely in the cutaneous sensation of touch (pp. 920, 921). Growth of a hair occurs at the hair bulb, where the cells capping the papilla proliferate and form the *germinal matrix* of the hair. As the daughter cells become progressively displaced upwards they become keratinised to form the fibre-like cornified cells of the shaft of the hair. The duration of life of a single hair varies from about 4 months (eyelashes, axillary hair) to about 4 years (scalp hair), after which it is shed and is replaced by the sprouting of new cells from the germinal matrix. Growth of a hair varies with its texture, ranging from about 1.5 mm. (fine hair) to 2.2 mm. (coarse hair) a week. Greying or whitening of hair is due to the collection of minute air bubbles in the cortex (and medulla) of the shaft and to loss of pigment (melanin) formation by cells in the germinal matrix (see p. 1296).

Minute bundles of involuntary muscular fibres, termed the *Arrectores pilorum* (figs. 1070, 1073), are connected with the hair-follicles. They arise from the superficial layer of the corium, and are inserted into the outer coat of the hair-follicle, below the entrance of the duct of the sebaceous gland. They are placed on the side towards which the hair slopes, and by their action diminish the obliquity of the follicle and elevate the hair. When they contract the skin over their origin is depressed, while the skin immediately around the hair is elevated; this results in the appearance of 'goose skin' seen on exposure to cold or in emotional reactions. The sebaceous gland is situated in the angle which the Arrector muscle forms with the superficial portion of the hair-follicle, and contraction of the muscle thus tends to squeeze the sebaceous secretion out from the duct of the gland. The Arrector muscles are supplied by sympathetic nerves.

The *sebaceous glands* (fig. 1073) are small, sacculated, glandular organs, lodged in the substance of the corium. They are found in most parts of the skin, but are especially abundant in the scalp and face; they are also very numerous around the apertures of the anus, nose, mouth and external ear, but are wanting in the palms of the hands and soles of the feet. Each gland consists of a single duct,

more or less capacious, which emerges from a cluster of oval or flask-shaped alveoli, usually from two to five, but in some instances as many as twenty in number. Each alveolus is composed of a transparent basement-membrane, enclosing a number of epithelial cells. The outer or marginal cells are small and polyhedral, and are continuous with the cells lining the duct. The remainder of the alveolus is filled with larger cells, containing fat, but in its centre the cells are broken up, leaving a cavity filled with their debris and a mass of fatty matter, which constitutes the *sebum cutaneum*. As the sebaceous glands produce their secretion by complete fatty degeneration of their central cells they are classed as *holocrine* glands. As the central cells disintegrate, they are replaced by proliferation of the marginal cells. The ducts open most frequently into the hair-follicles, the glands being developed as diverticula from the epithelial walls of the follicles themselves, but occasionally upon the general surface, as in the labia minora, glans penis and the free margins of the lips. On the nose and face the glands are of large size, distinctly lobulated, and often become much enlarged from the accumulation of pent-up secretion. The tarsal glands of the eyelids are elongated, sebaceous glands with numerous, lateral diverticula. Sebum acts as a natural lubricant of the hair and skin and protects the skin from the effects of moisture or desiccation; it also has some bacteriocidal action. The secretory activity of the sebaceous glands does not appear to be under nervous control; it is stimulated by hormonal action, particularly androgens.

The **sweat glands** (figs. 1070 and 1073) are found in almost every part of the skin, and are situated in small pits on the under surface of the corium, or, more frequently, in the subcutaneous tissue, surrounded by a quantity of adipose tissue. Each consists of a single tube, the deep part of which is rolled into an oval or spherical ball, named the *body* of the gland, while the superficial part, or *duct*, traverses the corium and epidermis and opens on the surface of the skin by a funnel-shaped aperture. In the superficial layers of the corium the duct is straight, but in the deeper layers it is convoluted or twisted; where the epidermis is thick, as in the palms of the hands and soles of the feet, the part of the duct which passes through it is spirally coiled. The size of the glands varies. They are especially large in those regions where the amount of perspiration is great, as in the axillæ, where they form a thin, mamillated layer of a reddish colour, which corresponds exactly with the situation of the hair in this region; they are large also in the groin. Their number varies. They are very plentiful on the palms of the hands, and on the soles of the feet, where the orifices of the ducts are exceedingly regular, and open on the curved ridges of the epidermis; they are least numerous in the neck and back. The tube, both in the body of the gland and in the duct, consists of two layers—an outer, of fine areolar tissue, and an inner, of epithelium. The outer layer is thin and is continuous with the superficial stratum of the corium. In the body of the gland the epithelium consists of a single layer of cubical cells, between the deep ends of which and the basement-membrane there is a layer of longitudinally or obliquely arranged elongated spindle-shaped cells, believed to be muscular and called myo-epithelial cells. The ducts are destitute of muscular fibres, and are composed of a basement-membrane lined by two or three layers of polyhedral cells; the duct passes through the epidermis as a spiral channel which is simply an intercellular cleft between the epidermal cells. When the epidermis is carefully removed from the surface of the corium, the ducts may be drawn out in the form of short, thread-like processes on its under surface.

The ceruminous glands of the external auditory meatus are modified sweat glands.

Most of the sweat glands are *merocrine* in nature, i.e. produce their thin watery secretion without demonstrable changes in the gland epithelium. In the region of the anterior axillary fold and in the scrotal and peri-anal skin are some larger glands which produce their rather thicker secretion by degeneration and shedding of the portion of the epithelial cell nearest the lumen. Such glands are termed *apocrine*. In the female they show involution changes related to each menstrual cycle. They are developed in close association with hairs and their ducts sometimes open into hair-follicles. Sweat glands are concerned in the temperature control mechanism by surface evaporation of the sweat. They are supplied by sympathetic nerves, though these are cholinergic in nature (p. 1199), and no sweating occurs in a denervated area of skin. Rarely, sweat glands may be congenitally absent, in which case special means have to be adopted to prevent rise of body temperature in hot weather.

SPLANCHNOLOGY

THE RESPIRATORY SYSTEM

THE respiratory system includes the two lungs and a series of air passages viz. the nasal cavities (pp. 299-303; 1224-1235), the pharynx (pp. 1380-1390), the larynx and the trachea and its divisions (the bronchi, bronchioles, etc.).

THE LARYNX

The **larynx**, which is the organ of the voice as well as an air-passage, extends from the root of the tongue to the trachea. It projects forwards between the great vessels of the neck, and is covered anteriorly by the skin, the fasciæ, and the depressor muscles of the hyoid bone (fig. 1075). Above, it opens into the laryngeal part of the pharynx, of which it forms the anterior wall; below, it is continuous with the trachea. In the adult male it is situated opposite the third, fourth, fifth and sixth cervical vertebræ, but it occupies a somewhat higher position in the child and in the adult female. In infants of between six and twelve months the tip of the epiglottis (the highest part of the larynx) is a little above the level of the cartilaginous disc between the odontoid process and the body of the axis. Its average measurements in the adult are as follows:

	In males.	In females.
Length	44 mm.	36 mm.
Transverse diameter	43 "	41 "
Anteroposterior diameter	36 "	26 "

Until puberty the larynx of the male differs little in size from that of the female. In the female its increase at puberty is only small. In the male the increase is considerable; all the cartilages enlarge and the thyroid cartilage projects in the anterior median line of the neck, while the anteroposterior diameter is nearly doubled.

The skeletal framework of the larynx is formed of cartilages, which are connected by ligaments and membranes, and are moved by numerous muscles. It is lined with mucous membrane continuous above and behind with that of the pharynx and below with that of the trachea.

The **cartilages of the larynx** are nine in number, three single and three paired, viz.:

Thyroid.	Two Arytenoid.
Cricoid.	Two Corniculate.
Epiglottis.	Two Cuneiform.

The **thyroid cartilage** (figs. 1075, 1077, 1078, 1087) is the largest cartilage of the larynx. It consists of two quadrilateral *laminae*, the lower parts of the anterior borders of which are fused at an angle in the median plane to form a subcutaneous projection named the *laryngeal prominence* (Adam's apple). This prominence is most distinct at its upper part, and is well marked in the male but scarcely visible in the female. Immediately above it the laminae are separated by a V-shaped notch, termed the *thyroid notch*. Posteriorly the laminae diverge and the posterior border of each is prolonged as two slender processes, the *superior* and *inferior horns*.

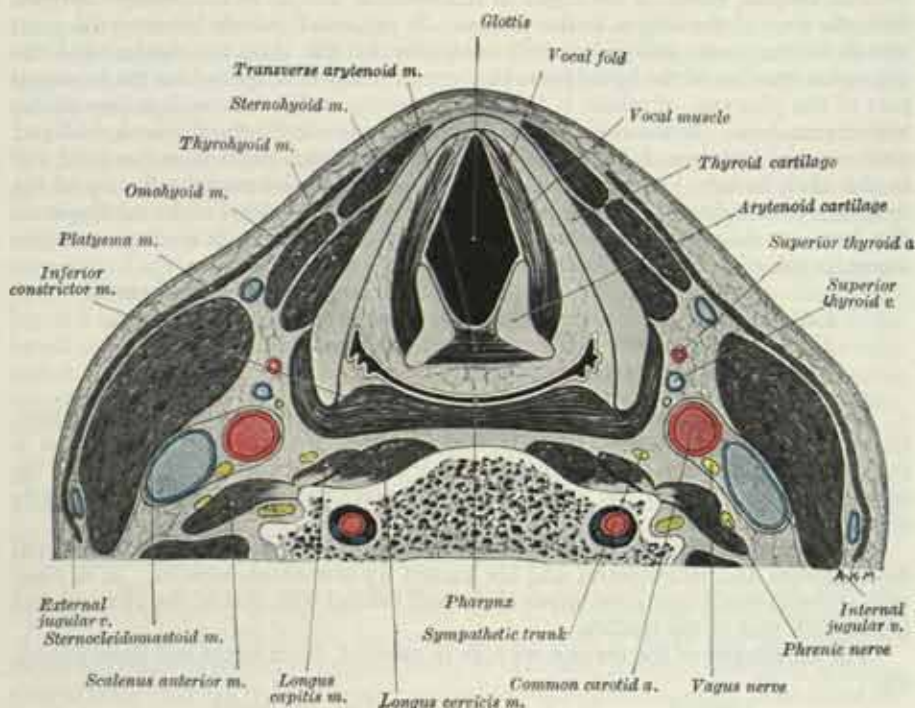
On the *outer surface* of each lamina an *oblique line* runs downwards and forwards from the *superior thyroid tubercle*, which is situated a little in front of the root of the superior horn, to the *inferior thyroid tubercle* on the lower border of the lamina. This line gives insertion to the Sternothyroid and origin to the Thyrohyoid and Inferior constrictor muscle of the pharynx. The *inner surface* is smooth: above and behind, it is slightly concave and covered with mucous membrane. In the upper part of the angle formed by the junction of the laminae, the thyro-epiglottic ligament is attached; below this, and on either side of the mid-line, the vestibular and vocal

ligaments and the Thyroarytenoid, Thyro-epiglottic and Vocal muscles gain attachment.

The *upper border* of each lamina is concave behind and convex in front; it gives attachment to the corresponding half of the thyrohyoid membrane. The *lower border* is concave behind, and nearly straight in front, the two parts being separated by the inferior thyroid tubercle. In and near the median plane it is connected to the cricoid cartilage by the cricothyroid ligament.

The *anterior border* is fused with that of the opposite lamina, forming with it an angle of about 90° in men, and about 120° in women. In men the greater projection of the laryngeal prominence, the greater length of the vocal fold and the resultant deeper pitch of the voice are all associated with the smaller size of the thyroid angle. The *posterior border*, thick and rounded, receives the insertions of fibres of the Stylopharyngeus and Palatopharyngeus muscles. The *superior horn*, long and narrow, is

FIG. 1075.—A transverse section across the anterior part of the neck at the level of the vocal folds.



directed upwards, backwards and medially, and ends in a conical extremity, which gives attachment to the lateral thyrohyoid ligament. The *inferior horn*, short and thick, is directed downwards, with a slight inclination forwards and medially; on the medial surface of its lower end there is a small oval facet for articulation with the side of the cricoid cartilage.

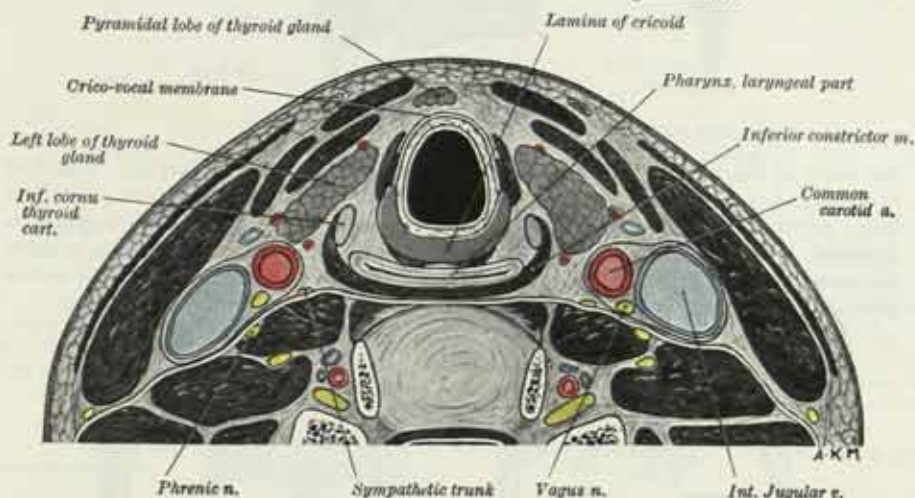
During infancy a narrow, lozenge-shaped, flexible strip, named the *intra-thyroid cartilage*, occupies the interval between the two laminae anteriorly and is joined to them by connective tissue.

The **cricoid cartilage** (figs. 1079 to 1082) is smaller, but thicker and stronger than the thyroid cartilage. It is shaped like a signet-ring, and forms the lower parts of the anterior and lateral walls and most of the posterior wall of the larynx. It comprises a quadrate posterior lamina, and a narrow anterior arch.

The *lamina* of the cricoid cartilage is deep and broad, and measures vertically from 2 cm. to 3 cm.; the posterior surface is marked by a median, vertical ridge, to the upper part of which the two fasciculi of the longitudinal fibres of the oesophagus are attached by a tendon (p. 1394). On each side of the ridge there is a shallow depression for the origin of the Posterior cricoarytenoid. The *arch* is narrow in front, measuring vertically from 5 mm. to 7 mm., but widens posteriorly as it

approaches the lamina. The external surface affords attachment in front and at the side to the Cricothyroid muscle, and behind, to part of the Inferior constrictor of the pharynx. The arch of the cricoid can be felt easily in the living subject below the laryngeal prominence and separated from it by a slight depression which corresponds to the cricothyroid ligament. On each side, at the junction of the lamina with the arch, there is a prominent circular facet, directed laterally and backwards, for articulation with the inferior horn of the thyroid cartilage. The lower border of the cricoid cartilage is horizontal, and connected to the highest ring of the trachea by the cricotracheal ligament. The upper border runs obliquely upwards and backwards. It gives attachment, in front, to the cricothyroid ligament; at the sides, to the cricovocal membrane and the Lateral cricoarytenoids; behind, it presents a median shallow notch, and on each side of this there is a smooth, oval, convex surface, directed upwards and laterally, for articulation with the base of the arytenoid cartilage. The inner surface of the cricoid cartilage is smooth and lined with mucous membrane.

FIG. 1076.—A transverse section through the anterior part of the neck, between the fifth and sixth cervical vertebræ. Semi-diagrammatic.



The paired **arytenoid cartilages** (figs. 1079, 1081) are placed on the upper border of the lamina of the cricoid cartilage, at the back of the larynx. Each is pyramidal in form, and has three surfaces, a base and an apex.

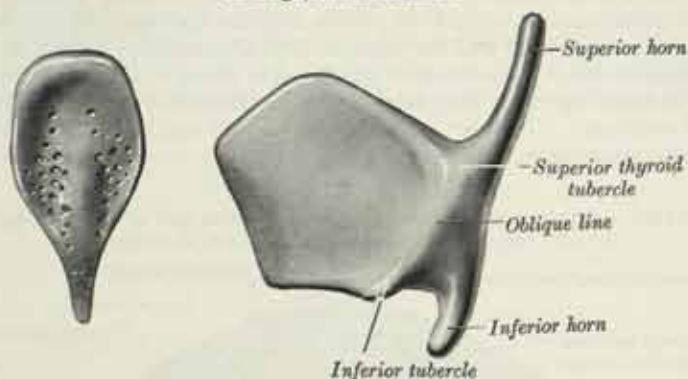
The *posterior surface*, triangular, smooth and concave, is covered with the Transverse arytenoid. The *anterolateral surface* is somewhat convex and rough. On it, near the apex of the cartilage, there is an elevation from which a crest curves at first backwards and then downwards and forwards to the vocal process. The lower part of this crest intervenes between two depressions or foveæ, an upper, triangular, and a lower, oblong in shape; the upper gives attachment to the vestibular ligament; the lower to the Vocal and Lateral cricoarytenoid muscles. The *medial surface* is narrow, smooth and flat; it is covered with mucous membrane, and its lower edge forms the lateral boundary of the intercartilaginous part of the rima glottidis (p. 1313). The *base* is concave, and presents a smooth surface for articulation with the upper border of the lamina of the cricoid cartilage. Its lateral angle or *muscular process*, rounded and prominent, projects backwards and laterally, and gives insertion to the Posterior cricoarytenoid behind, and to the Lateral cricoarytenoid in front. Its anterior angle or *vocal process* is pointed; it projects horizontally forwards and gives attachment to the vocal ligament. The *apex* curves backwards and medially, and articulates with the *corniculate cartilage*.

The **corniculate cartilages** (figs. 1081, 1082) are two small conical nodules of elastic fibrocartilage which articulate with the summits of the arytenoid cartilages and serve to prolong them backwards and medially. They are situated in the posterior parts of the aryepiglottic folds of mucous membrane, and are sometimes fused with the arytenoid cartilages.

The **cuneiform cartilages** (fig. 1082) are two small, elongated, club-shaped pieces of elastic fibrocartilage, placed one in each aryepiglottic fold, where they give rise to whitish elevations on the surface of the mucous membrane, just in front of the corniculate cartilages.

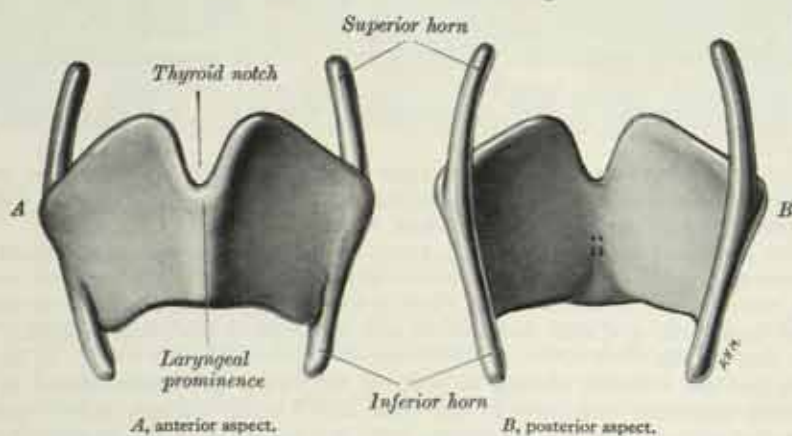
The cartilage of the **epiglottis** (figs. 1077, 1081, 1082) is a thin, leaf-like lamella of elastic fibrocartilage, which projects obliquely upwards behind the tongue and

FIG. 1077.—The epiglottis, posterior surface, and the left lamina of the thyroid cartilage, lateral surface.



the body of the hyoid bone, and in front of the entrance to the larynx. The free extremity, broad and rounded, is directed upwards; the attached part or stalk is long, narrow, and connected by an elastic ligament, named the *thyro-epiglottic ligament*, to the angle formed by the two laminae of the thyroid cartilage, a short distance below the thyroid notch. The sides of the epiglottis are attached to the arytenoid cartilages by the aryepiglottic folds of mucous membrane (p. 1309).

FIG. 1078.—The thyroid cartilage.



The attachments of the vestibular ligaments (above) and the vocal ligaments (below) are shown in B.

The upper part of the *anterior surface* of the epiglottis is free, and covered with mucous membrane, which is reflected on to the pharyngeal part of the tongue and on to the lateral wall of the pharynx, forming a *median glosso-epiglottic fold* and two *lateral glosso-epiglottic folds*. The depression on each side of the median glosso-epiglottic fold is named the *vallecula*. The lower part of the anterior surface lies behind the hyoid bone and the thyrohyoid membrane, and is connected to the upper border of the hyoid bone by an elastic ligament, named the *hyo-epiglottic ligament*; it is separated from the thyrohyoid membrane by some fatty tissue.

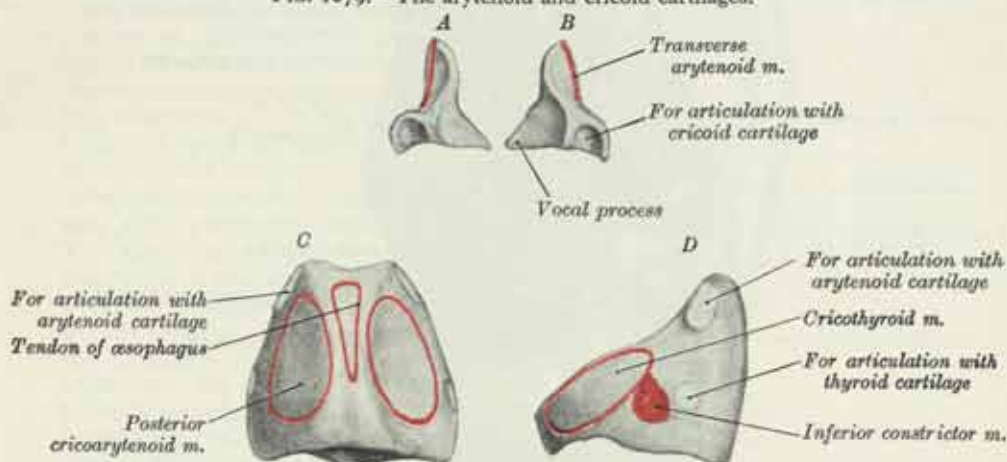
The *posterior surface* of the epiglottis is smooth, concave from side to side, concavoconvex from above downwards, and covered with mucous membrane; its lower part projects backwards as an elevation, known as the *tubercle*. When the

mucous membrane is removed, the cartilage is seen to be indented by a number of small pits in which mucous glands are lodged. The cartilage is perforated by branches of the internal laryngeal nerve.

Function of the epiglottis.*—During deglutition (p. 1390) the epiglottis moves upwards and forwards and is squeezed between the base of the tongue and the rest of the larynx, the bolus slipping over its posterior surface and over the closed inlet of the larynx. In man, it is degenerate in function and is separated from the soft palate by a long interval; it is not essential for deglutition, which can take place normally even if the epiglottis is destroyed by disease; neither is it essential for respiration or phonation. Some mammals are keen-scented even when the mouth is open for feeding. In these, the epiglottis is large and projects into the nasal part of the pharynx above the soft palate; when eating, the epiglottis is drawn downwards and forwards (by the hyo-epiglottic muscle, represented in man by the hyo-epiglottic ligament) against the upper surface of the soft palate, so keeping the nasal airway clear and the mouth airway closed. The function of the epiglottis in these animals is thus to preserve the integrity of the olfactory sense even when the mouth is open.

Structure.—The corniculate and cuneiform cartilages, the epiglottis, and the apices of the arytenoids consist of elastic fibrocartilage, which shows little tendency to

FIG. 1079.—The arytenoid and cricoid cartilages.



A, the left arytenoid cartilage, medial aspect. B, the right arytenoid cartilage, medial aspect. C, the cricoid cartilage, posterior aspect. D, the cricoid cartilage, left lateral aspect.

calcification. The thyroid, cricoid, and the greater part of the arytenoids consist of hyaline cartilage, and become more or less ossified as age advances. Ossification commences about the twenty-fifth year in the thyroid cartilage, and somewhat later in the cricoid and the arytenoids; by the sixty-fifth year these cartilages may be converted completely into bone. The ossified parts of these cartilages are visible in radiographs (Pl. I).

Joints.—The joints between the inferior horns of the thyroid cartilage and the sides of the cricoid cartilage are synovial, and each is enveloped by a capsular ligament, which is strengthened posteriorly by a fibrous band. At these joints the cricoid rotates upon the inferior horns of the thyroid cartilage around an axis passing transversely through both joints; to a limited extent the cricoid also glides in different directions on the horns of the thyroid.

A pair of synovial joints exist between the facets on the upper border of the lamina of the cricoid cartilage and the bases of the arytenoid cartilages; each joint is enclosed by a capsular ligament, and a strong *posterior cricoarytenoid ligament* connects the cricoid cartilage with the medial and posterior part of the base of the arytenoid cartilage. These joints permit of two varieties of movement: one is a rotation of the arytenoid on a vertical axis, whereby the vocal process is moved laterally or medially, and the rima glottidis increased or diminished; the other is a gliding movement, and allows the arytenoid cartilages to approach or recede from each other; from the direction and slope of the articular surfaces lateral gliding is

* V. E. Negus, *J. Anat. Lond.*, 62, 1-8, 1927.

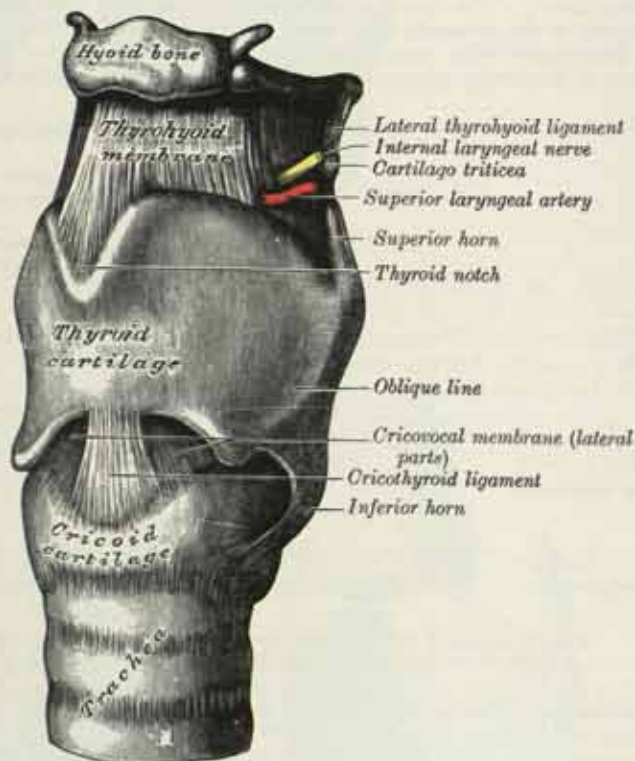
accompanied by a forward and downward movement. The two movements of gliding and rotation are associated, the medial gliding being connected with medial rotation, and the lateral gliding with lateral rotation. The posterior cricoarytenoid ligaments limit the forward movements of the arytenoid cartilages on the cricoid cartilage.

A cartilaginous, sometimes a synovial, joint exists between the apex of each arytenoid cartilage and the corresponding corniculate cartilage.

Ligaments and membranes.—(figs. 1080, 1081).

Extrinsic ligaments.—The *thyrohyoid membrane* is a broad, fibro-elastic layer, attached below to the upper border of the thyroid cartilage and to the front of its superior horns, and above to the *upper* margin of the posterior surface of the body

FIG. 1080.—The ligaments of the larynx. Anterolateral aspect.



and greater horns of the hyoid bone. As it ascends, it passes behind the concave posterior surface of the body of the hyoid bone, and is separated from it by a bursa, which facilitates the upward movement of the larynx during deglutition. The middle, thicker, part of the membrane is termed the *median thyrohyoid ligament*; on each side the lateral thinner portion is pierced by the superior laryngeal vessels and the internal laryngeal nerve. Its outer surface is in relation with the Thyrohyoid, Sternohyoid and Omohyoid muscles, and with the body of the hyoid bone. Its inner surface is related to the epiglottis and the piriform fossa of the pharynx.

The *lateral thyrohyoid ligaments* are round elastic cords which form the posterior borders of the thyrohyoid membrane, and connect the tips of the superior horns of the thyroid cartilage to the posterior ends of the greater horns of the hyoid bone. A small cartilaginous nodule, termed the *cartilago triticea*, is frequently found in each ligament.

The epiglottis is attached to the hyoid bone by the hyo-epiglottic ligament and to the thyroid cartilage by the thyro-epiglottic ligament (p. 1306).

The *cricotracheal ligament* unites the lower border of the cricoid cartilage with the first ring of the trachea. It is continuous below with the fibrous membrane which invests the rings of the trachea.

Intrinsic ligaments.—Beneath the mucous membrane of the larynx there is a broad sheet of fibrous tissue which contains many elastic fibres, and is termed the *fibro-elastic membrane of the larynx*. It is subdivided on each side by the interval between the vestibular and vocal ligaments; the upper portion extends between the arytenoid cartilage and the cartilage of the epiglottis, and is often poorly defined; the lower part is a well-marked membrane forming, with its fellow of the opposite side, the *cricovocal membrane*, which connects the thyroid, cricoid and arytenoid cartilages one to another. The joints between the individual cartilages are also provided with ligaments, already described.

The *cricovocal membrane* (fig. 1082) is composed mainly of yellow elastic tissue. It consists of an anterior and two lateral parts. The *anterior part*, or *cricothyroid ligament*, is thick and strong, narrow above and broad below. It connects the front parts of the contiguous margins of the thyroid and cricoid cartilages. It is overlapped on each side by the Cricothyroid, but between these muscles it is subcutaneous; its upper part is crossed by a small arterial arch, formed by the junction of the two cricothyroid arteries; branches of this arch pierce the ligament. The *lateral part* of the cricovocal membrane is thinner; it is lined with the mucous membrane of the larynx, and is covered with the Cricoarytenoid and Thyroarytenoid. Below it is attached to the inner edge of the superior border of the cricoid cartilage. Its upper edge is attached, in front, to the deep surface of the thyroid angle and, behind, to the inferior surface and tip of the vocal process of the arytenoid cartilage.

Between these two attachments, the upper edge of the lateral part of the cricovocal membrane is free and is thickened slightly to form the *vocal ligament* (fig. 1082).

The *cavity of the larynx* (figs. 1083, 1084) extends from the laryngeal inlet, by which it communicates with the pharynx, to the level of the lower border of the cricoid cartilage, where it is continuous with the cavity of the trachea. It is divided into three parts by an upper and a lower pair of folds of mucous membrane which project from the sides of the cavity into its interior. The upper folds are named the *vestibular folds*, and the fissure between them is called the *rima vestibuli*. The lower folds are concerned in the production of the voice, and are therefore named the *vocal folds*, and the fissure between them is called the *rima glottidis*.

The *inlet of the larynx* [aditus laryngis] (fig. 1085) is the aperture through which the laryngeal cavity opens into the pharynx. The plane of the aperture is directed backwards and very slightly upwards, for the anterior wall of the larynx is much longer than its posterior wall and slopes downwards and forwards in its upper part (fig. 1083). The opening is bounded anteriorly by the upper edge of the epiglottis, posteriorly by the mucous membrane stretching between the arytenoid cartilages, and on each side by the free edge of a fold of mucous membrane which stretches between the side of the epiglottis and the apex of the arytenoid cartilage and contains some ligaments and muscular fibres; this is the *aryepiglottic fold*, and on the posterior

FIG. 1081.—The ligaments of the larynx.
Posterior aspect.

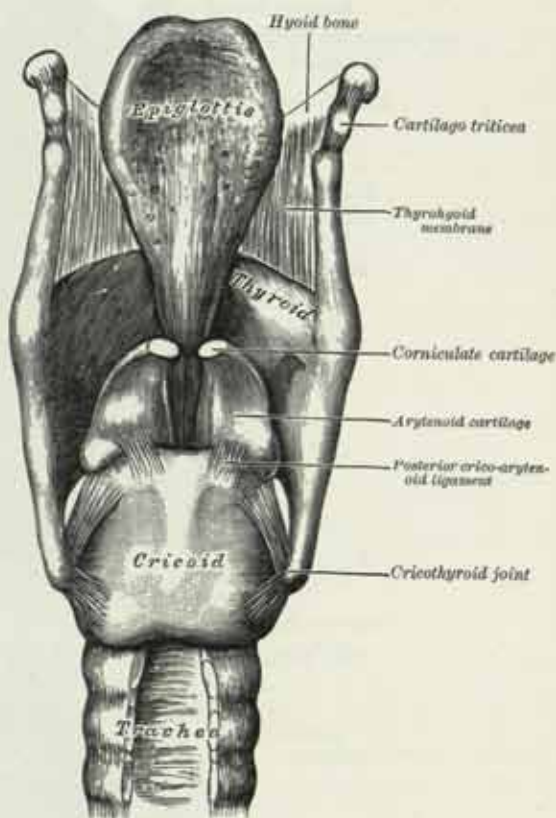


FIG. 1082.—A dissection to show the right half of the cricovocal membrane. The right lamina of the thyroid cartilage and the subjacent muscles have been removed.

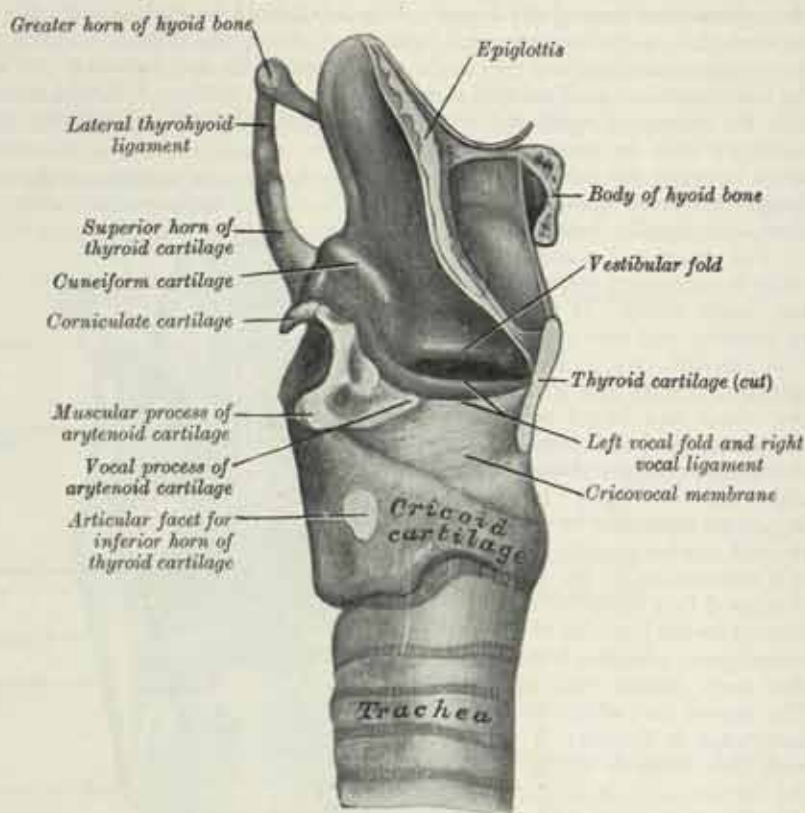
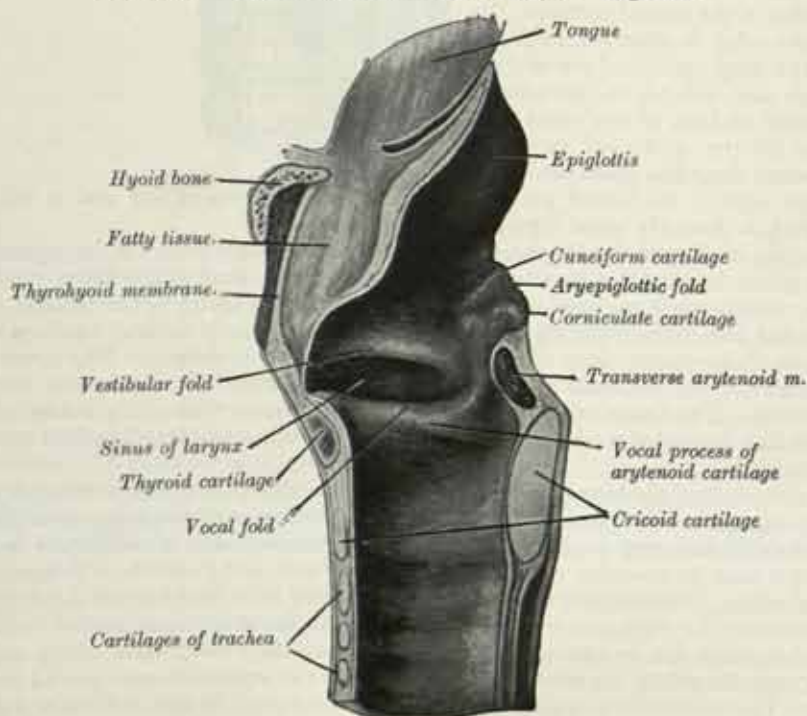


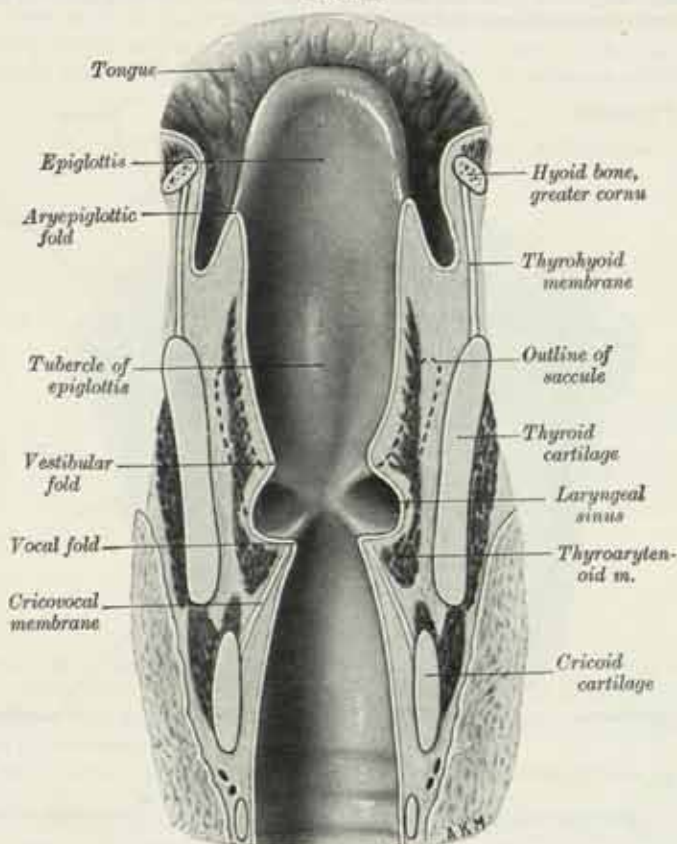
FIG. 1083.—A sagittal section through the larynx. Right half.



part of its free margin there are two oval elevations, an anterior produced by the cuneiform cartilage, and a posterior by the corniculate cartilage. These elevations are separated by a shallow vertical furrow, which is continuous below with the opening into the sinus of the larynx. (See also p. 1390.)

The *vestibule of the larynx* (figs. 1083, 1084) is the part between the laryngeal inlet and the level of the vestibular folds; it is wide above, and narrow below. Its anterior wall is much deeper than its posterior wall and consists of the posterior surface of the epiglottis, the lower part of which projects backwards as the tubercle (p. 1306). Its lateral walls, deep in front and shallow behind, are formed by the medial surfaces of the aryepiglottic folds; its posterior wall consists of the mucous

FIG. 1084.—A coronal section through the larynx and the uppermost part of the trachea.



The anterior half of the section is viewed from behind.

membrane connecting the arytenoid cartilages, above the level of the vestibular folds.

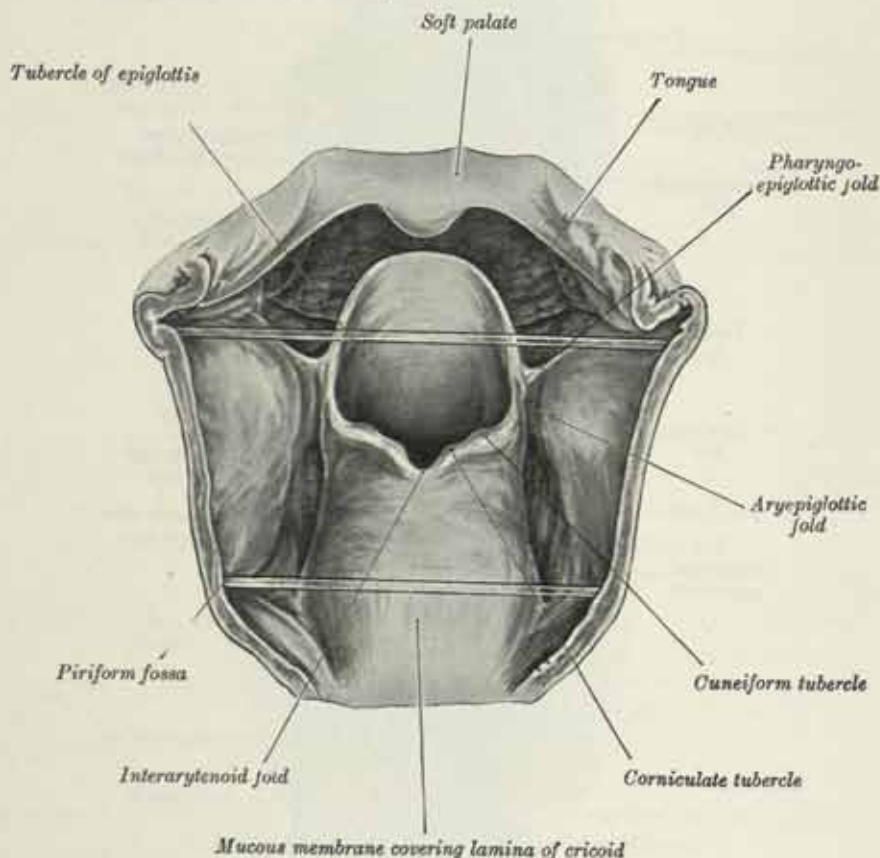
The *middle part* of the laryngeal cavity is the smallest. It reaches from the level of the rima vestibuli to that of the rima glottidis. On each side it opens, through a slit between the vestibular and vocal folds, into a recess which is named the sinus of the larynx.

The *sinus of the larynx* (figs. 1083, 1084) is a fusiform recess which lies between the vestibular and vocal folds, and ascends for a short distance outside the vestibular fold. It is lined with mucous membrane, clothed on the outside by the corresponding Thyroarytenoid muscle. From the anterior part of the sinus a narrow opening leads upwards into the saccule of the larynx.

The *saccule of the larynx* (fig. 1084) is a pouch which ascends from the anterior part of the sinus, between the vestibular fold and the inner surface of the thyroid cartilage, occasionally extending as high as the upper border of the cartilage; it is conical in form, and curved slightly backwards. On the surface of its mucous mem-

brane there are the openings of sixty or seventy mucous glands, which are lodged in the submucous areolar tissue. The sacculus is enclosed in a fibrous capsule continuous below with the vestibular ligament. Its medial surface is covered by a few delicate muscular fasciculi, which arise from the apex of the arytenoid cartilage and, passing forwards between the sacculus of the larynx and the mucous membrane of the vestibule, become lost in the aryepiglottic fold; laterally it is separated from the thyroid cartilage by the Thyroepiglottic muscle. These muscles compress the sac and express the secretion of its glands upon the vocal fold to lubricate its surfaces. In most apes the sacculi are remarkably developed in the form of air sacs, which may extend into the superficial tissues of the neck and even into the axillæ;

FIG. 1085.—The inlet of the larynx, viewed from behind. The posterior wall of the pharynx has been divided in the median plane and two glass rods have been inserted to keep the cut portions apart.



they appear to affect the resonance of the voice. In man, the sacculi occasionally protrude through the thyrohyoid membrane.

The *vestibular folds* (figs. 1082, 1083, 1084) are two thick, pink folds of mucous membrane, each enclosing a narrow band of fibrous tissue, termed the *vestibular ligament*, which is fixed in front to the angle of the thyroid cartilage immediately below the attachment of the epiglottic cartilage, and behind to the anterolateral surface of the arytenoid cartilage, a short distance above the vocal process.

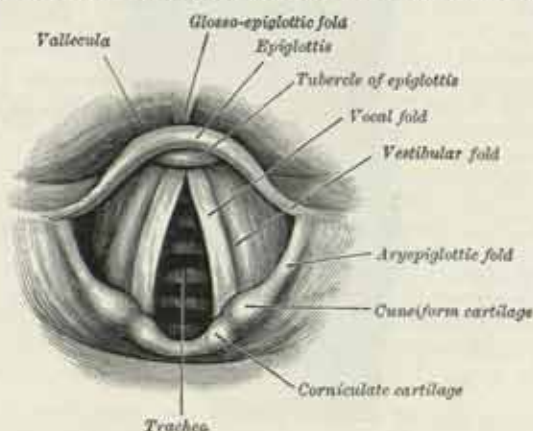
The *vocal folds* (figs. 1082, 1083, 1084) are two sharp, white folds of mucous membrane which stretch from the middle of the angle of the thyroid cartilage to the vocal processes of the arytenoid cartilages. They form the lateral boundaries of the rima glottidis in its anterior part and are concerned in the production of the voice. The stratified squamous epithelium which covers the vocal fold is closely bound down to the underlying vocal ligament. As a result of the absence of a submucous layer and blood-vessels, the vocal fold is pearly white in colour in the living subject.

The *vocal ligament*, which is continuous below with the lateral part of the cricovocal membrane (p. 1309), consists of a band of yellow elastic tissue, related, on its lateral side, to the Vocal muscles (p. 1314).

The *rima glottidis* (fig. 1086) is a fissure situated between the vocal folds anteriorly, and between the bases and vocal processes of the arytenoid cartilages posteriorly; it is limited behind by the mucous membrane passing between the arytenoid cartilages, at the level of the vocal folds. The portion between the vocal folds is named the *intermembranous part*, and measures about three-fifths of the length of the entire aperture; that between the arytenoid cartilages is named the *intercartilaginous part*. The average length of the rima glottidis, in the adult male, is 23 mm.; in the adult female, 17 mm. It is the narrowest part of the larynx, but its width and shape vary with the movements of the vocal folds and arytenoid cartilages during respiration and phonation (see p. 1315).

The *lower part* of the laryngeal cavity extends from the level of the vocal folds to the lower border of the cricoid cartilage. Its upper part is elliptical in form, but its lower part widens, assumes a circular shape, and is continuous with the cavity of

FIG. 1086.—A laryngoscopic view of the interior of the larynx.



the trachea. It is lined with mucous membrane, and its walls consist of the cricovocal membrane above, and the inner surface of the cricoid cartilage below.

Muscles.—The muscles of the larynx are divisible into two groups:—(1) *extrinsic* and (2) *intrinsic*.

(1) The extrinsic muscles pass between the larynx and neighbouring structures, and are described in the section on Myology (pp. 569–572).

(2) The intrinsic muscles are: *Cricothyroid*; *Posterior cricoarytenoid*; *Lateral cricoarytenoid*; *Transverse arytenoid*; *Oblique arytenoid* and its subdivision the *Aryepiglottic*; *Thyroarytenoid* and its subdivision the *Vocal muscle* and the *Thyroepiglottic*. With the exception of the Transverse arytenoid these muscles are paired.

The *Cricothyroid* (fig. 1087), triangular in form, arises from the front and lateral part of the outer surface of the cricoid cartilage; its fibres diverge, and are arranged in two groups. The lower fibres constitute the *oblique part* and slant backwards and laterally to the anterior border of the inferior horn, while the anterior fibres form the *straight part* and run upwards and backwards to the posterior part of the lower border of the lamina of the thyroid cartilage.

The medial borders of the two muscles are separated by a triangular interval occupied by the subcutaneous part of the cricothyroid ligament.

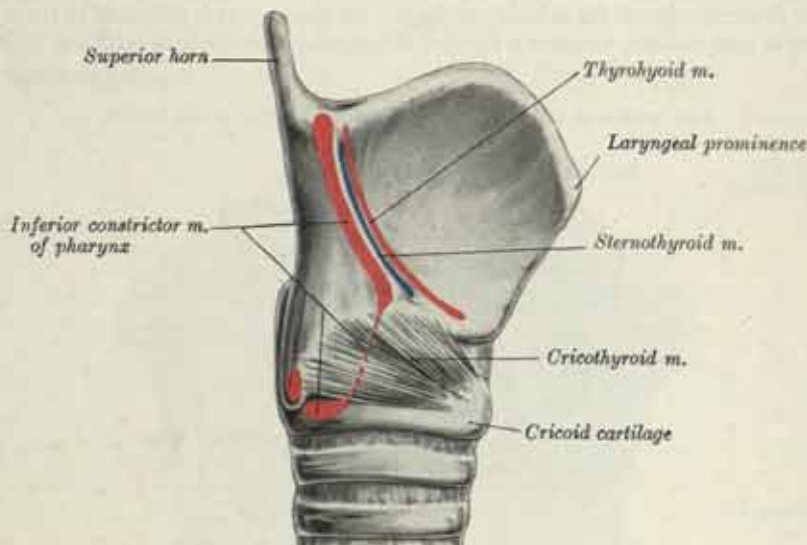
The *Posterior cricoarytenoid* (fig. 1088) arises from the lower and medial part of the broad depression on the corresponding half of the posterior surface of the lamina of the cricoid cartilage; its fibres, directed upwards and laterally, converge to be inserted into the back of the muscular process of the arytenoid cartilage. The highest fibres are nearly horizontal, the middle oblique and the lowest almost vertical; some of the latter fibres are inserted into the anterolateral surface of the arytenoid cartilage.

The *Lateral cricoarytenoid* (fig. 1089) is smaller than the preceding muscle; it arises from the upper border of the arch of the cricoid cartilage, and, passing obliquely upwards and backwards, is inserted into the front of the muscular process of the arytenoid cartilage.

The *Transverse arytenoid* (fig. 1088) is a single muscle which bridges the interval between the arytenoid cartilages and fills the posterior concave surfaces of these cartilages. It arises from the back of the muscular process and lateral border of the arytenoid cartilage of one side, and is inserted into the corresponding parts of the cartilage on the opposite side.

The *Oblique arytenoid* (fig. 1088), superficial to the Transverse arytenoid, consists of two fasciculi which cross each other like the limbs of the letter X. Each passes

FIG. 1087.—A side view of the larynx, showing the muscular attachments.



from the back of the muscular process of one arytenoid cartilage to the apex of the opposite cartilage. Some of the fibres are continued round the lateral margin of the apex of the arytenoid cartilage, and are prolonged into the aryepiglottic fold; they constitute the *Aryepiglottic* muscle.

The *Thyroarytenoid* (fig. 1089) is a broad, thin muscle, which is situated lateral to the vocal fold, the cricovocal membrane, the sinus and the sacculus of the larynx. It arises in front from the lower half of the angle of the thyroid cartilage, and from the cricothyroid ligament. Its fibres pass backwards, laterally and upwards, to be inserted into the anterolateral surface of the arytenoid cartilage. The lower and deeper fibres of the muscle form a band which, in a coronal section, appears as a triangular bundle, and is attached to the lateral surface of the vocal process and to the inferior impression on the anterolateral surface of the arytenoid cartilage. This bundle is named the *Vocal* muscle, and is parallel with, and just lateral to, the vocal ligament; it is thicker behind than in front, because many of its deeper fibres take origin from the vocal ligament, and so do not extend so far forwards as the thyroid cartilage. A considerable number of the fibres of the Thyroarytenoid are prolonged into the aryepiglottic fold, where some of them are lost, while others are continued to the margin of the epiglottis, forming the *Thyroepiglottic* muscle. A few fibres extend along the wall of the sinus from the lateral margin of the arytenoid cartilage to the side of the epiglottis. The *Superior thyroarytenoid* (fig. 1089), which is not always present, is a small muscle, lying on the lateral surface of the main mass of the Thyroarytenoid and extending obliquely from the angle of the thyroid cartilage to the muscular process of the arytenoid cartilage.

Actions.*—The muscles of the larynx may be conveniently divided into three

* V. E. Negus, *Proc. Roy. Soc. Med.*, 40, 849, 1947.

groups according to their main actions, (1) those which open and close the glottis, viz. the *Posterior* and *Lateral Cricoarytenoids* and the *Arytenoids*; (2) those which regulate the degree of tension of the vocal ligaments, viz. the *Cricothyroids*, the *Posterior Cricoarytenoids*, the *Thyroarytenoids* and the *Vocal muscles*; (3) those which modify the inlet of the larynx, viz. the *Aryepiglottics* and the *Thyroepiglottics* (fig. 1090). It is to be noted that, under normal conditions, the corresponding muscles of the two sides always work together.

The *Posterior cricoarytenoids* open the glottis, by rotating the arytenoid cartilage laterally, around a vertical axis passing through the cricoarytenoid joints, so that the vocal processes and the attached vocal folds are separated. They also brace back the arytenoids, thus assisting the *Cricoarytenoids* in making the vocal folds tense. The most lateral fibres of the muscle draw the arytenoids laterally, so that the entire rima glottidis becomes triangular (not lozenge-shaped) when the *Posterior cricoarytenoids* contract.

The *Lateral cricoarytenoids* close the glottis, by rotating the arytenoid cartilages medially so as to approximate the vocal processes.

The *Transverse arytenoid* approximates the arytenoid cartilages, and thus closes the opening of the glottis, especially at its posterior part.

The *Cricothyroids* produce tension and elongation of the vocal ligaments by drawing up the arch of the cricoid cartilage and tilting back the upper border of its lamina; the distance between the vocal processes and the angle of the thyroid is thus increased, and the vocal ligaments are consequently put on the stretch. They also pull the thyroid cartilage forward, increasing the distance between the angle of the thyroid cartilage and the arytenoids; this action also renders the vocal folds tense. Negus believes this latter action of the muscle is the principal one, because during phonation the lamina of the cricoid is held immovably against the vertebral column by the action of the *Cricopharyngeus* (p. 1387). During swallowing, the *Cricopharyngeus* relaxes and allows the cricoid to be tilted forward during closure of the inlet of the larynx. The *Cricothyroids* also rotate the arytenoids medially, thus adducting the vocal folds.

The *Thyroarytenoids* draw the arytenoid cartilages forwards towards the thyroid, and thus shorten and relax the vocal ligaments. At the same time they rotate the arytenoid cartilages medially and approximate the vocal folds. The deeper fibres, forming the *Vocal muscles*, produce relaxation of the posterior parts of the vocal ligaments, while the anterior part is tense, the effect being to raise the pitch of the voice.

The *Oblique arytenoids* and the *Aryepiglottic muscles* act as a sphincter of the inlet of the larynx, by bringing the aryepiglottic folds together, and by approximating the arytenoid cartilages to the tubercle of the epiglottis.

The *Thyroepiglottics* widen the inlet of the larynx by their action on the aryepiglottic folds.

Movements of the vocal folds (fig. 1090).—In the condition of rest, e.g. in quiet respiration, the intermembranous part of the rima glottidis is triangular, its apex being in front and its base behind, the base being represented by a line (about 8 mm. long) connecting the anterior ends of the vocal processes of the arytenoids; the intercartilaginous part is rectangular since the medial surfaces of the arytenoids are parallel.

In forced inspiration, the vocal folds undergo extreme abduction; the arytenoid cartilages are rotated laterally and their vocal processes move widely apart. The glottis is thus lozenge-shaped; both intermembranous and intercartilaginous parts are triangular, the widest part of the aperture being opposite the attachments of the folds to the vocal processes of the arytenoids.

The movements of the vocal folds during phonation have been studied by high-speed motion photographs.* Preparatory to phonation the intermembranous and intercartilaginous parts of the glottis are reduced to a linear chink by adduction of the vocal folds, and adduction and medial rotation of the arytenoid cartilages. This is followed by tightening of the folds, the degree of tension determining the pitch of the sound. As the pitch rises, the tension of the folds increases and they may lengthen by as much as 50 per cent. in the highest notes. The photographs suggest that the lengthening affects both extremities of the folds, indicating that the *Cricothyroid* muscles act not only on the cricoid cartilage as above described but also tilt the thyroid cartilage downwards and forwards. In whispering, the inter-

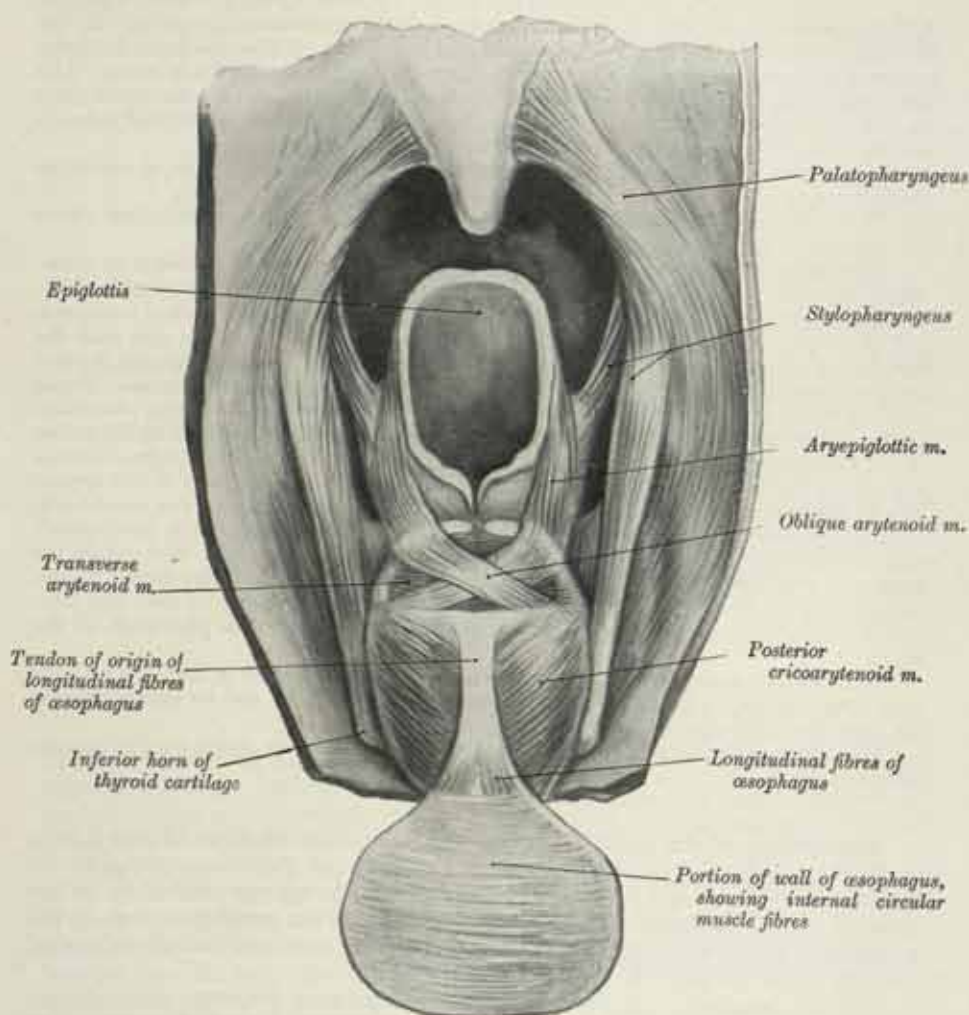
* J. J. Pressman, *Arch. Otolaryngol.*, 35, 1942.

membranous part of the glottis is closed, but the intercartilaginous part remains widely patent, so that there is free escape of air during the process.

The movements of the larynx, and the manner in which its inlet is closed during deglutition, are described on p. 1390.

Mucous Membrane.—The mucous membrane of the larynx is continuous above with that of the mouth and pharynx, below with that of the trachea. It is loosely

FIG. 1088.—The muscles of the larynx. Posterior aspect,



attached to the anterior surface of the epiglottis, and to the underlying tissues in the valleculæ. It covers the aryepiglottic folds, which bound the inlet of the larynx; in these folds there is a considerable amount of areolar tissue. It lines the cavity of the larynx, forms, by its reduplication, the chief parts of the vestibular folds, and is continued into the sinus and sacculus of the larynx. It is firmly attached to the posterior surface of the epiglottis and to the laryngeal surfaces of the cuneiform and arytenoid cartilages. The parts covering the vocal ligaments are thin and intimately adherent to them. On the anterior surface, and the upper half of the posterior surface, of the epiglottis, the upper part of the aryepiglottic folds, and the vocal folds, the epithelium of the mucous membrane is of the stratified squamous type; patches of stratified squamous epithelium are also found above the glottis. The rest of the laryngeal mucous membrane is covered with ciliated columnar epithelium.

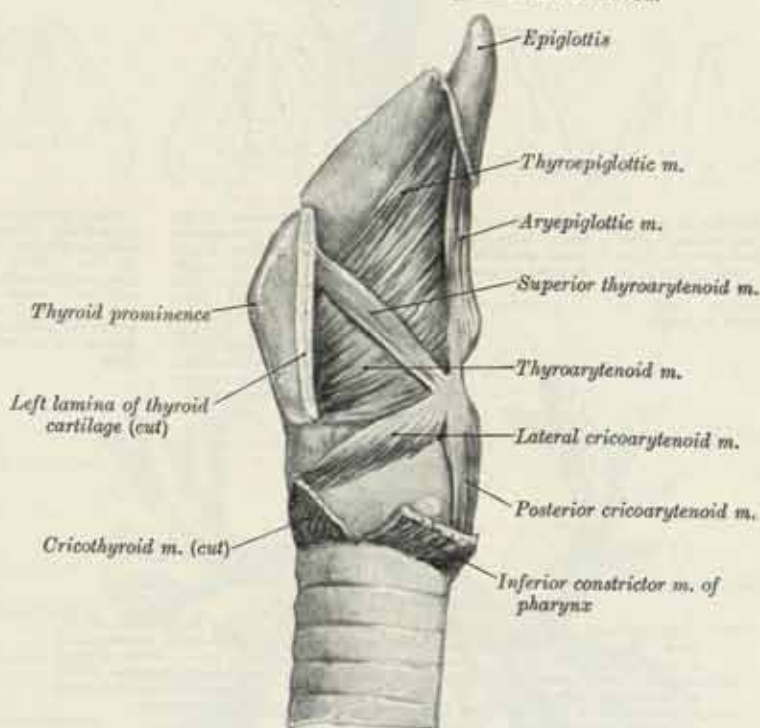
Glands.—The mucous membrane of the larynx is furnished with numerous mucous glands; they are very plentiful upon the epiglottis, where they are lodged in little

pits; many are present in the margins of the aryepiglottic folds in front of the arytenoid cartilages, where they are termed the *arytenoid glands*. They are large and numerous in the saccules of the larynx and secretion has been observed to flow down over the vocal folds periodically during phonation. The free edges of the vocal folds are devoid of glands.

Taste-buds, similar to those in the tongue, are scattered over the posterior surface of the epiglottis, in the aryepiglottic folds, and less regularly in some other parts of the larynx.

Vessels and Nerves.—The chief *arteries* of the larynx are the laryngeal branches of the superior and inferior thyroid arteries. The *veins* accompanying the superior laryngeal artery join the superior thyroid vein, which opens into the internal jugular vein; those accompanying the inferior laryngeal artery join the inferior thyroid vein,

FIG. 1089.—The muscles of the larynx. Viewed from the left side. Most of the left lamina of the thyroid cartilage has been removed.

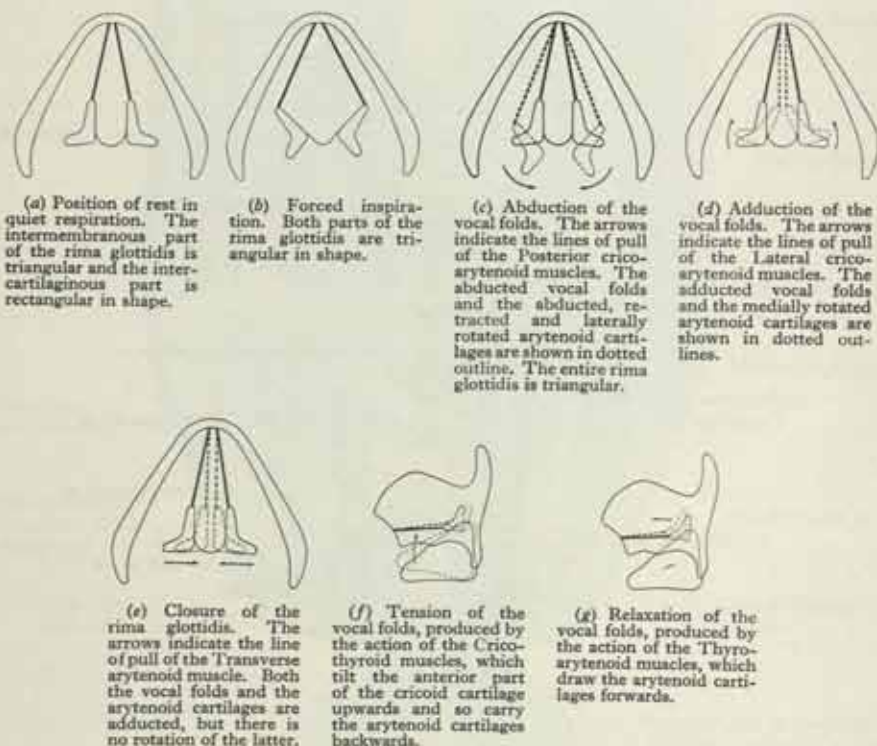


which opens into the left brachiocephalic vein. The *lymph vessels* are divisible into two sets, a superior above the vocal folds, and an inferior below; the superior vessels accompany the superior laryngeal artery, pierce the thyrohyoid membrane, and end in the deep cervical lymph nodes situated near the bifurcation of the common carotid artery; some of the inferior lymph vessels pierce the cricothyroid ligament and open into a lymph node lying in front of that ligament or in front of the upper part of the trachea, while others emerge below the cricoid cartilage and pass to the deep cervical lymph nodes and to the lymph nodes alongside of the inferior thyroid artery. The *nerves* are derived from the internal and external branches of the superior laryngeal nerve, from the recurrent laryngeal nerve and from the sympathetic. The internal laryngeal branch is probably entirely sensory, though some claim that motor filaments are carried by it to the Arytenoids. It enters the larynx through the postero-inferior part of the thyrohyoid membrane above the superior laryngeal artery, and divides into branches which supply both surfaces of the epiglottis, the aryepiglottic fold, and the interior of the larynx down as far as the level of the vocal folds. The external laryngeal branch supplies the Cricothyroid by entering its lateral surface. The terminal part of the recurrent laryngeal nerve accompanies the laryngeal branch of the inferior thyroid artery, and passes upwards deep to the lower border of the inferior constrictor muscle, immediately behind the cricothyroid joint. It supplies all the intrinsic muscles of the larynx except the Cricothyroid, and distributes sensory branches to the laryngeal mucous membrane below the level of the vocal folds. See also footnote, p. 1133.)

Laryngoscopic examination.—The inlet of the larynx, the structures surrounding it, and the cavity of the larynx can be inspected with a laryngoscopic mirror. The epiglottis is much foreshortened (fig. 1086), but its tubercle can be seen in the median plane. From the margins of the epiglottis the aryepiglottic folds can be traced backwards and medially and, at their posterior extremities, the elevations produced by the cuneiform and the corniculate cartilages can be recognised. The pink vestibular folds and the pearly white vocal folds are visible within the cavity of the larynx and, when the rima glottidis is opened widely, the rings of the trachea come into view. The piriform fossæ of the pharynx can also be inspected.

Radiography.—In lateral radiographs, in addition to the ossified parts of the laryngeal cartilages, the epiglottis, aryepiglottic folds, arytenoid, corniculate and (sometimes) cuneiform cartilages, and the laryngeal sinus are visible.

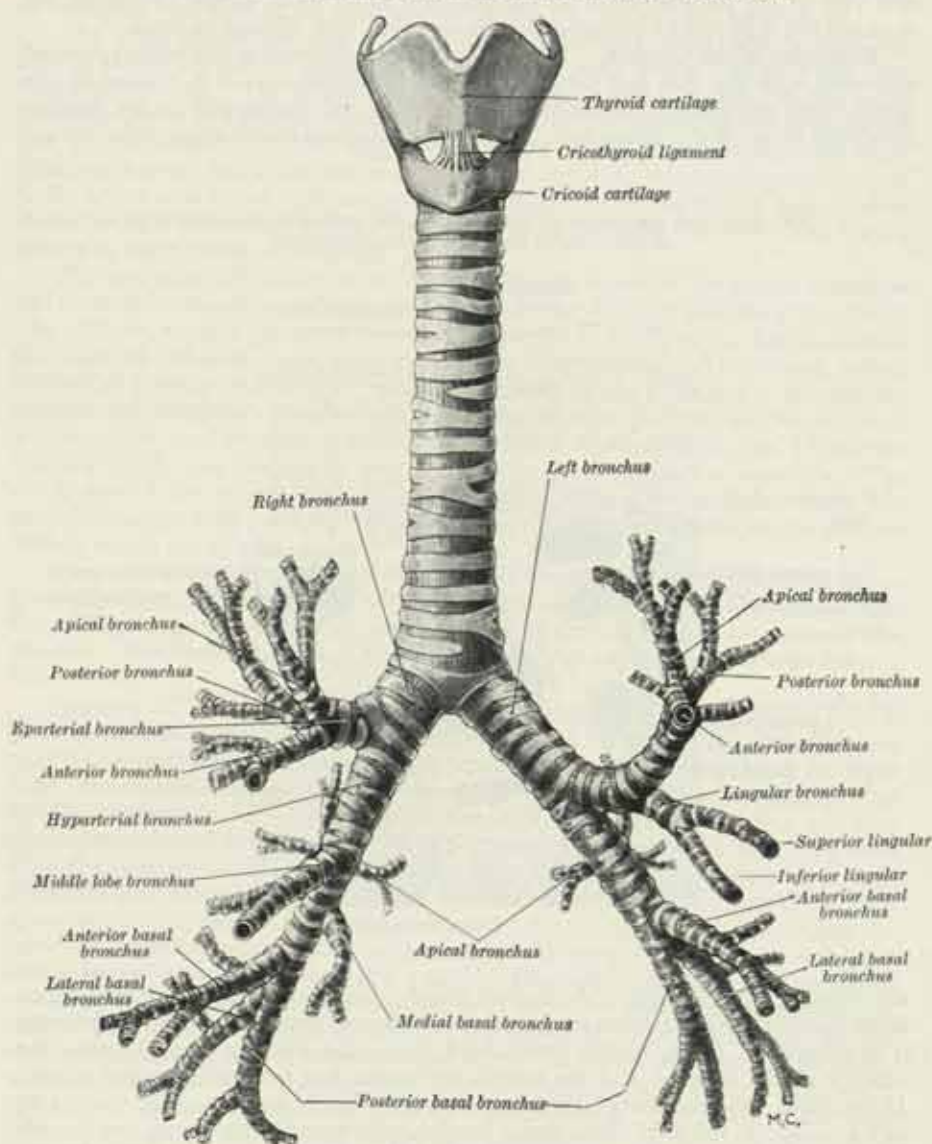
FIG. 1090.—A series of diagrams to show different positions of the vocal folds and arytenoid cartilages.



Surface and Applied Anatomy.—In and near the mid-line of the neck the following structures are readily identified (fig. 567). The laryngeal prominence (Adam's apple) can be felt easily; it is visible in men but not always in women. The anterior parts of the upper borders of the laminae of the thyroid cartilage and the thyroid notch are palpable. (The vocal folds lie opposite about the middle of the anterior border of the thyroid cartilage.) Above the thyroid, the body of the hyoid and its greater cornua can be palpated, the latter most readily by gripping the throat at this level between the thumb and finger. The thyrohyoid membrane lies in the depression between the thyroid cartilage and the hyoid. Below the thyroid, the arch of the cricoid can be felt; it is on a level with the lower part of the cricoid lamina and lies opposite the body of the sixth cervical vertebra. The depression between the cricoid and thyroid corresponds to the cricothyroid ligament. Below the cricoid the first ring of the trachea can be felt. Foreign bodies may become impacted in the inlet of the larynx or in the rima glottidis and cause suffocation by mechanical obstruction. Small bodies may pass down into the trachea or bronchi, or lodge in the laryngeal sinus and, by irritating the mucous membrane, cause reflex spasm of the glottis with consequent suffocation. Inflammation of the upper part of the larynx may cause considerable swelling of the mucous membrane through effusion of fluid into the abundant lax submucous tissue; this condition is called 'œdema of the glottis'. The effusion does not involve, or extend below, the vocal folds, since the mucous membrane is closely adherent to the vocal

ligaments without the intervention of any submucous tissue. In the above cases, an incision into the larynx below the vocal folds through the cricothyroid membrane (laryngotomy) or into the trachea (tracheotomy) may be necessary to restore a free air-way. The mucous membrane of the upper part of the larynx is extremely sensitive and contact with foreign bodies causes an immediate explosive cough. In suicidal cut-throat the wound is usually through the thyrohyoid membrane with damage to

FIG. 1091.—The cartilages of the larynx, trachea, and bronchi. Anterior aspect.
Drawn from a cast made *in situ* in fusible metal by R. C. Brock.



the epiglottis, superior thyroid vessels, external and internal carotids and internal jugular veins; less frequently it is above the hyoid with damage to the tongue muscles and the lingual and facial vessels. (For results of damage to the laryngeal nerves, see p. 1136.)

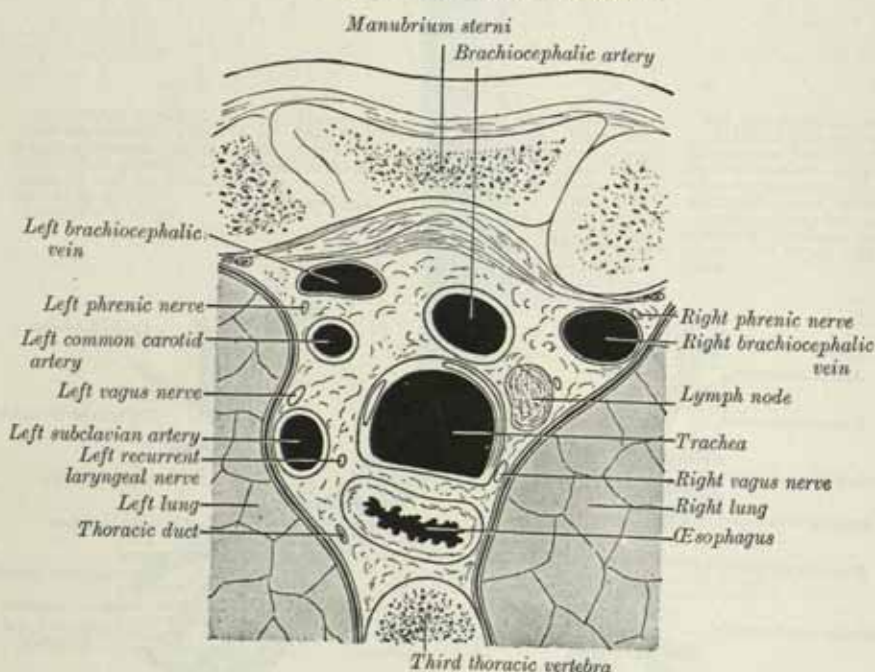
THE TRACHEA AND BRONCHI (fig. 1091)

The **trachea**, or **windpipe**, is a cartilaginous and membranous tube, about 10 or 11 cm. long, continued downwards from the lower part of the larynx. In the cadaver it reaches from the level of the sixth cervical vertebra to that of the upper border of the fifth thoracic vertebra, where it divides into two bronchi, one for each

lung. The trachea, for the main part, lies in the median plane, though its point of bifurcation usually lies a little to the right of the median plane. In the living subject during deep inspiration the bifurcation descends and may come to lie opposite the sixth thoracic vertebra. The trachea is not quite cylindrical, being flattened posteriorly; its external diameter from side to side is about 2 cm. in the adult male, and 1.5 cm. in the adult female. In the child the trachea is smaller, more deeply placed and more movable than in the adult. In the living the lumen is smaller than in the cadaver, its diameters in the adult being about 12 mm. In the first year of life the diameters do not exceed 3 mm., while during childhood the diameters in millimetres correspond approximately with the age in years.

Relations of the trachea.—The *cervical part* of the trachea (fig. 682) is covered anteriorly with the skin and the superficial and deep fasciæ. It is crossed by the jugular arch connecting the anterior jugular veins and overlapped by the Sternohyoid and Sternothyroid muscles. The second, third and fourth rings of the trachea

FIG. 1092.—A transverse section through the mediastinum at the level of the body of the third thoracic vertebra.



are crossed by the isthmus of the thyroid gland; immediately above the isthmus an anastomosing vessel connects the two superior thyroid arteries; below the isthmus it is related, in front, to the pretracheal fascia, the inferior thyroid veins, the remains of the thymus, and the arteria thyreoidea ima (when that vessel exists). In the child, the brachiocephalic artery crosses obliquely in front of the trachea at, or a little above, the level of the upper border of the manubrium sterni, and the left brachiocephalic vein may extend a little above the upper border of the manubrium. Posteriorly the trachea is related to the oesophagus, which intervenes between it and the vertebral column; the recurrent laryngeal nerves ascend, one on each side, in the grooves between the sides of the trachea and the oesophagus. Laterally the trachea is related to the lobes of the thyroid gland, which descend to the level of the fifth or sixth tracheal ring, and to the common carotid and inferior thyroid arteries.

The *thoracic part* of the trachea (figs. 1092, 1094) descends through the superior mediastinum. In front, it is related to the manubrium sterni, the origins of the Sternothyroid muscles, the remains of the thymus, the inferior thyroid veins, the left brachiocephalic vein, the arch of the aorta, the brachiocephalic and left common

carotid arteries, the deep part of the cardiac plexus of nerves, and some lymph nodes. Owing to the divergence of the brachiocephalic and left common carotid arteries as they ascend in the neck, the former vessel comes to lie on the right, and the latter on the left of the trachea. *Behind*, it is related to the œsophagus, by which it is separated from the vertebral column. On the *right* it is related to the right lung and pleura, the right vagus nerve, and the azygos vein: on the *left* to the arch of the aorta, the left common carotid and left subclavian arteries. The left recurrent laryngeal nerve, in its upward course, lies at first between the trachea and the arch of the aorta, and then in the groove between the trachea and the œsophagus.

The **right bronchus** (fig. 1091), wider, shorter and more vertical than the left, is about 2.5 cm. long, and enters the right lung nearly opposite the fifth thoracic vertebra. The greater width and more vertical course of the right bronchus result in a greater tendency for foreign bodies to pass into the right than into the left bronchus. The azygos vein arches over it from behind; the right pulmonary artery lies at first below and then in front of it. After giving off a branch to the upper lobe of the right lung—termed the *eparterial bronchus* because it arises above the right pulmonary artery—the bronchus passes below the artery, and is then known as the *hyarterial bronchus*.

The eparterial bronchus arises from the lateral aspect of the parent bronchus and runs upwards and laterally for about 1 cm. before dividing into *three* branches.* One of these, termed the *apical bronchus*, is directed upwards with a lateral inclination towards the apex of the lung, to which it is distributed. The second, which serves the postero-inferior part of the upper lobe of the lung and is termed the *posterior* (or *subapical*) *bronchus*, is directed backwards, laterally and slightly upwards. Very soon after its origin it divides into a lateral branch, and a posterior branch, which runs backwards and divides into upper and lower branches. The third, termed the *anterior bronchus*, runs downwards and forwards to supply the rest of the upper lobe; not far from its origin it divides into a lateral and an anterior branch which are of equal size.†

About 2 cm. below the origin of the eparterial bronchus, the hyarterial bronchus gives off a branch to the middle lobe of the right lung (fig. 1091). It springs from the anterior aspect of the parent trunk and is directed forwards, downwards and laterally. It soon divides into a *medial* branch to the medial part of the lobe and a *lateral* branch to its lateral portion.

Opposite to, or a little below the origin of the bronchus to the middle lobe, a large *apical* branch arises from the dorsal surface of the hyarterial bronchus and runs backwards to be distributed to the upper part of the lower lobe of the right lung. Below this a subapical or posterior bronchus is sometimes found and it may be large in the right lung. Between the origin of the subapical bronchus and that of the lateral basal bronchus one or two accessory segmental bronchi may arise from the lobar stem to be distributed to the subapical area, the lobar stem continuing as the posterior basal bronchus. In the left lung the upper part of the subapical segmental bronchus may be overlaid by the apical segment above and the posterior basal segment below; in these cases the peripheral distribution is seen on the lateral aspect of the lung (fig. 1093).† Thereafter the hyarterial bronchus continues downwards, backwards and laterally for 2 cm. and then divides into an *anterior basal* branch, directed downwards and forwards, and a trunk which divides almost immediately into a *posterior basal* branch, directed downwards and backwards, and a *lateral basal* branch, directed laterally and downwards. At its terminal division the hyarterial bronchus gives off a small branch, termed the *medial basal* (or *cardiac*) branch, which runs downwards and medially to serve a small area of the medial part of the lower lobe below the hilus of the lung.

The **left bronchus** (fig. 1091), narrower than the right, is nearly 5 cm. long, and enters the root of the left lung opposite the sixth thoracic vertebra. It passes below the aortic arch, and crosses in front of the œsophagus, the thoracic

* For a detailed description of the branches of the bronchi, their variations and their clinical significance, consult a series of papers by R. C. Brock and others, *Guy's Hospital Reports*, 91, 1942; 92, 1943, and 93, 1944, summarised in *The Anatomy of the Bronchial Tree* by R. C. Brock, Ox. Univ. Press, 1954. Also E. A. Boyden, *Segmental Anatomy of the Lungs*, McGraw-Hill Book Co. Inc., 1955.

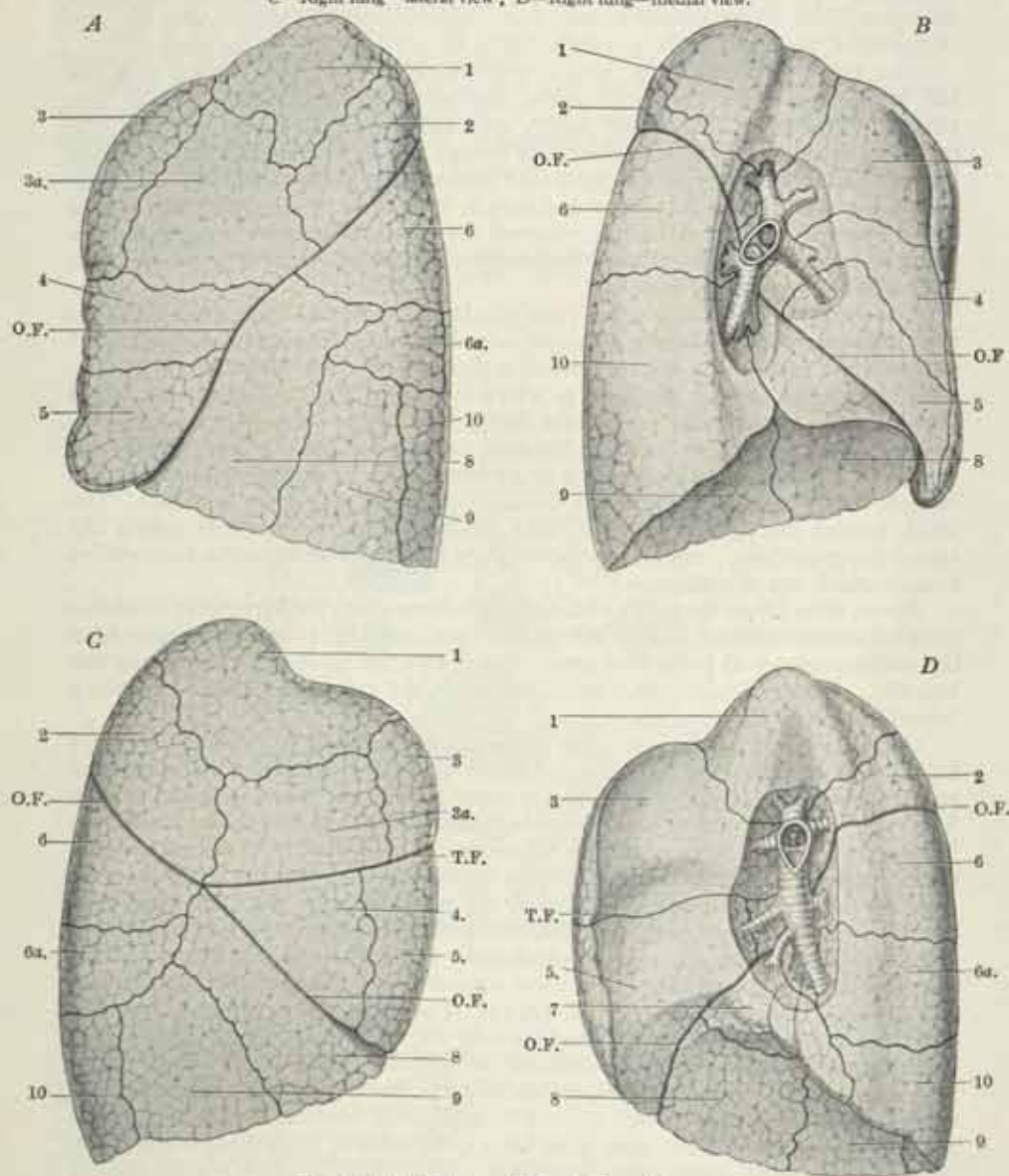
† J. Hardie-Neil and W. Gilmour, *New Zealand Med. J.*, 45, 20, 1946; *Brit. Med. J.*, 2, 399, 1949; J. Hardie-Neil, W. Gilmour and F. J. Gwynne, *Brit. Med. J.*, i, 495, 1939.

duct, and the descending thoracic aorta; the left pulmonary artery lies at first above, and then in front of it. The left bronchus has no eparterial branch.

About 5 cm. from its origin the left bronchus gives off a large branch from

FIG. 1093.—Diagrams of the lungs showing the broncho-pulmonary segments.

A—Left lung—lateral view; B—Left lung—medial view;
C—Right lung—lateral view; D—Right lung—medial view.



O.F. = Oblique fissure. T.F. = Horizontal fissure.

Broncho-pulmonary segments:

- 1 = Apical (of upper lobe)
- 2 = Posterior
- 3 and 3a = Anterior
(3 = anterior branch)
(3a = lateral branch)
- 4 = Lateral (in right lung); Superior lingular
(in left lung)

- 5 = Medial (in right lung); Inferior lingular
(in left lung)
- 6 = Apical (of lower lobe)
- 6a = Subapical of lower lobe
- 7 = Medial basal (or Cardiac)
- 8 = Anterior basal
- 9 = Lateral basal
- 10 = Posterior basal

its anterolateral surface. This branch curves laterally for a short distance and then divides into two bronchi, which correspond to the branches which the right bronchus gives to the upper and middle lobes of the right lung. Both these bronchi are

distributed to the upper lobe of the left lung, which does not possess a separate middle lobe (p. 1337). The upper division ascends for 1 cm. before giving off an *anterior* (pectoral) branch, and then continues its upward course for a further 1 cm. as the *apicoposterior* branch before dividing into *apical* and *posterior* branches. The apical, posterior and anterior bronchi are distributed, for the most part, in a similar manner to the corresponding bronchi of the upper lobe of the right lung. The lower division of the left upper lobe bronchus runs downwards, forwards and

FIG. 1094.—A transverse section through the mediastinum at the level of the upper part of the body of the fourth thoracic vertebra.



laterally to be distributed to the lower and anterior part of the upper lobe of the left lung. It is known to clinicians as the *lingular bronchus*. Unlike the bronchus to the middle lobe of the right lung, which divides into anterior and lateral branches, the lingular bronchus, after giving off a small lateral branch, divides into upper and lower branches called the *superior lingular* and *inferior lingular* branches. These two bronchi maintain the direction of the lingular bronchus and end in the lingula itself.

Continuing downwards, and slightly laterally and backwards, the left bronchus gives off branches to the lower lobe of the left lung exactly corresponding with the branches distributed to the lower lobe of the right lung, except that the medial basal (or cardiac) branch is absent or, when present, is very small.

Each of the above-described branches of the right and left bronchi divides into ramifications that are distributed to self-contained, functionally-independent units of lung tissue, called *bronchopulmonary segments* (fig. 1093). The main bronchopulmonary segments (fig. 1093) are named and numbered as follows: *Right lung*. Upper Lobe—(1) Apical, (2) Posterior, (3) Anterior; Middle lobe—(4) Lateral, (5) Medial; Lower lobe—(6) Apical, (7) Medial basal (or Cardiac), (8) Anterior basal, (9) Lateral basal, (10) Posterior basal. *Left lung*. Upper lobe—(1) Apical, (2) Posterior, (3) Anterior, (4) Superior lingular, (5) Inferior lingular; Lower lobe—(6) Apical, (8) Anterior basal, (9) Lateral basal, (10) Posterior basal. (The absence of a medial basal or cardiac segment involves omission of segment 7 from the lower lobe of the left lung.) Each bronchopulmonary segment is surrounded by connective tissue (continuous with that of the visceral pleura) and forms a separate respiratory district of the lung. While infection may be restricted to one segment, malignant disease and tuberculosis break through from one segment to another. Recent advances in thoracic surgery * have shown the importance of these segments in connexion with certain diseases of the lungs. Use is also made of the anatomical topography of the branches of the bronchi in determining the necessary postures to be adopted by patients for promoting natural drainage of infected areas

* See footnotes on p. 1321.

of the lungs, and for the injection of radio-opaque substances (lipiodol) into various bronchopulmonary segments for diagnostic purposes. The segments of the upper lobes of the lungs supplied by the lateral and posterior branches of the posterior bronchus are common sites for lung abscess. The bronchus supplying the middle lobe of the right lung is comparatively narrow and short and is liable to occlusion from extrinsic pressure; it may also become compressed by enlargement of lymph nodes that surround it.

Structure (fig. 1095).—The trachea and extrapulmonary bronchi consist of a framework of incomplete rings of hyaline cartilage, united by fibrous tissue and unstriated muscle. They are lined by mucous membrane.

The *cartilages* of the trachea vary from sixteen to twenty in number. Each is an imperfect ring which occupies the anterior two-thirds or so of the circumference of the trachea; behind, where the rings are deficient, the tube is flat, and is completed by fibrous and elastic tissue and unstriated muscular fibres. The cartilages are placed horizontally one above another, and are separated by narrow intervals. They measure about 4 mm. in depth and 1 mm. in thickness; their external surfaces are flattened, but their internal surfaces are convex. Two or more of the cartilages often unite, partially or completely, and are sometimes bifurcated at their extremities. They are

highly elastic, but may become calcified in advanced life. In the extrapulmonary bronchi the cartilages are shorter and narrower than those of the trachea, but have the same shape and arrangement.

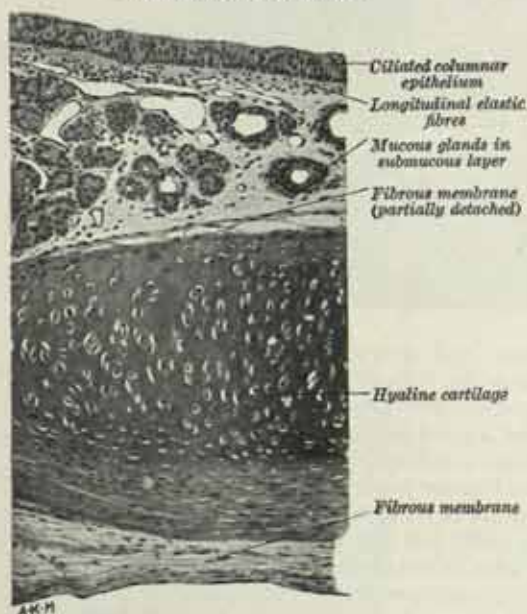
The first and the last tracheal cartilages differ from the others (fig. 1091). The *first cartilage* is broader than the rest, and often divided at one end; it is connected by the cricotracheal ligament with the lower border of the cricoid cartilage, with which or with the succeeding cartilage, it is sometimes blended. The *last cartilage* is thick and broad in the middle, where its lower border is prolonged into a triangular hook-shaped process which curves downwards and backwards between the two bronchi forming a ridge called the *carina*. It forms on each side an imperfect ring which encloses the commencement of the bronchus. The cartilage above the last is somewhat broader at its centre than the others.

The fibrous membrane.—The cartilages are enclosed in an elastic fibrous membrane which consists of two layers, one, the denser, passing over the outer surfaces of the rings, the other over the inner surfaces: at the upper and lower margins of the cartilages the two layers blend and form a stout membrane which connects the rings one with another. Where the cartilages are deficient posteriorly, the membrane forms a single layer. The trachea is highly elastic and is stretched longitudinally during respiration. The yellow elastic and white collagenous fibres of the elastic membrane are arranged in oblique decussating bundles, the angles of decussation being open in the unstretched and acute in the stretched trachea.

The *muscular tissue* is placed within the fibrous membrane at the posterior part of the tube, and consists of two layers of non-striated muscle, longitudinal and transverse. The *longitudinal fibres* are external, and consist of a few scattered bundles. The *transverse fibres* (*Tracheal muscle*) are internal, and form a thin layer which not only extends between the ends of the cartilages but also passes across in the intervals between the cartilages.

Mucous Membrane.—The mucous membrane is continuous above with that of the larynx, and below with that of the bronchi. It consists of areolar and lymphoid tissue, and presents a well-marked basement-membrane, supporting an epithelium, the surface cells of which are columnar and ciliated, with numerous mucus-secreting goblet-cells, while those of the deeper layers are oval or round. The cilia produce an upward flow of the mucus. Beneath the basement-membrane there is a layer of

FIG. 1095.—A transverse section through a part of the wall of the trachea.



longitudinal elastic fibres with a small amount of intervening areolar tissue. The *submucous layer* is composed of a loose mesh-work of connective tissue, containing large blood-vessels, nerves and mucous glands; the ducts of the latter pierce the overlying layers and open into the trachea.

Vessels and Nerves.—The trachea is supplied with blood mainly by the inferior thyroid arteries. The veins end in the inferior thyroid venous plexus. The lymph vessels pass to the pretracheal and paratracheal lymph nodes. The nerves are derived from the vagi and the recurrent laryngeal nerves, and from the sympathetic trunks; they are distributed to the Tracheal muscle and to the mucous membrane.

Surface and Applied Anatomy.—The trachea, about 2 cm. wide, extends from the cricoid cartilage almost vertically downwards in the median plane as far as the sternal angle; it inclines very slightly to the right as it descends. The right bronchus runs from the lower end of the trachea downwards and to the right for 2.5 cm. to reach the hilus of the lung opposite the sternal end of the right third costal cartilage. The left bronchus runs at a smaller angle from the lower end of the trachea for 5 cm. to the left and downwards to reach the hilus of the lung behind the left third costal cartilage, 3.5 cm. from the median plane. The trachea may be opened by a median vertical incision, either above the isthmus of the thyroid gland (high tracheotomy) or below it (low tracheotomy). The low operation is more troublesome because the trachea recedes from the surface as it descends and because of the anterior relations of this part of the tube, namely the inferior thyroid veins, the anastomosis between the anterior jugular veins, the arteria thyroidea ima (when present), and (in the child) the brachiocephalic artery, the left brachiocephalic vein and the thymus. The trachea may be compressed by pathological enlargements of structures related to it, e.g. the thyroid gland, the thymus and the arch of the aorta. (The radiological appearances of the trachea, bronchi and lungs are dealt with on p. 1342.)

THE PLEURÆ

Each lung is invested by a delicate serous membrane which is arranged in the form of a closed invaginated sac and is termed the **pleura**. A portion of this serous membrane covers the surface of the lung and lines the fissures between its lobes; it is called the *visceral or pulmonary pleura*. The rest of the membrane lines the inner surface of the corresponding half of the chest-wall, covers a large part of the Diaphragm, and is reflected over the structures occupying the middle part of the thorax; this portion is termed the *parietal pleura*. The pulmonary and parietal pleuræ are continuous with each other around and below the root of the lung; *in health they are in actual contact in all phases of respiration*, but the potential space between them is known as the *pleural cavity*. When the lung collapses or when air or fluid collects between the pulmonary and parietal pleuræ, the pleural cavity becomes apparent. The right and left pleural sacs are distinct from each other, and come into immediate contact only for a short distance behind the upper half of the body of the sternum (fig. 1096), although they are separated only by a narrow interval behind the œsophagus in the midthoracic region. The interval between the two sacs is named the *interpleural space* or *mediastinum*. The right pleural cavity is wider than the left, because the heart extends further to the left than to the right side. The upper and lower limits of the pleural sacs are approximately the same, but the left sac sometimes descends to a lower level in the mid-axillary line.

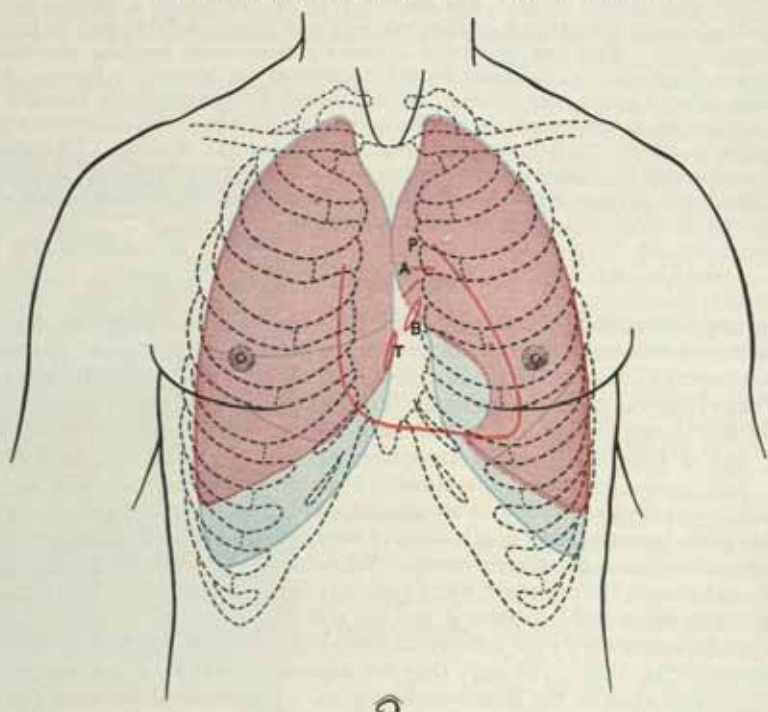
The **pulmonary pleura** is inseparably connected with the lung. It covers the surfaces of the lung, including those which bound the fissures between the lobes of the lung; it is absent, however, over an area where the lung root enters, and along a line extending downwards from this and marking the attachment of the pulmonary ligament (figs. 1107, 1108).

The **parietal pleura**.—Different portions of the parietal pleura have received distinctive names; the part lining the inner surfaces of the ribs and the Transversus thoracis (p. 584) is the *costal pleura*; that clothing the thoracic surface of the Diaphragm is the *diaphragmatic pleura*; that ascending into the neck over the summit of the lung is the *cervical pleura* (or *dome of the pleura*); and that applied to the structures occupying the interpleural space is the *mediastinal pleura*.

The *costal pleura* (figs. 1096, 1098) lines the sternum, ribs, the constituent parts of the Transversus thoracis, and the sides of the bodies of the vertebræ, and is easily separated from them. Outside the costal pleura there is a thin layer of loose areolar tissue, called the *endothoracic fascia*; it corresponds to the transversalis fascia of the abdominal wall. In front, the costal pleura begins behind the sternum where

it is continuous with the mediastinal pleura. The line of junction of the mediastinal with the costal pleura extends from behind the sternoclavicular joint downwards and medially to a point in the median plane behind the sternal angle. From this point the right and left costal pleurae descend in contact with each other as far as the level of the fourth costal cartilages, below which the line differs on the two sides. On the right side it is continued down to the posterior surface of the xiphisternal joint. On the left it diverges laterally and descends, close to or a short distance from the margin of the sternum, to the level of the sixth costal cartilage. On each side the costal pleura sweeps laterally, lining the inner surfaces of the costal cartilages, ribs and the constituent parts of the Transversus thoracis, and at the back of the thorax passes over the sympathetic trunk and its branches, and on to the sides of the bodies of the vertebrae, where it again becomes continuous with the mediastinal

FIG. 1096.—The front of the thorax, showing the surface relations of the bones, lungs (purple), pleurae (blue), and heart (red outline).



A. Orifice of aorta.

B. Left atrioventricular (mitral) orifice.

P. Orifice of pulmonary trunk.

T. Right atrioventricular (tricuspid) orifice.

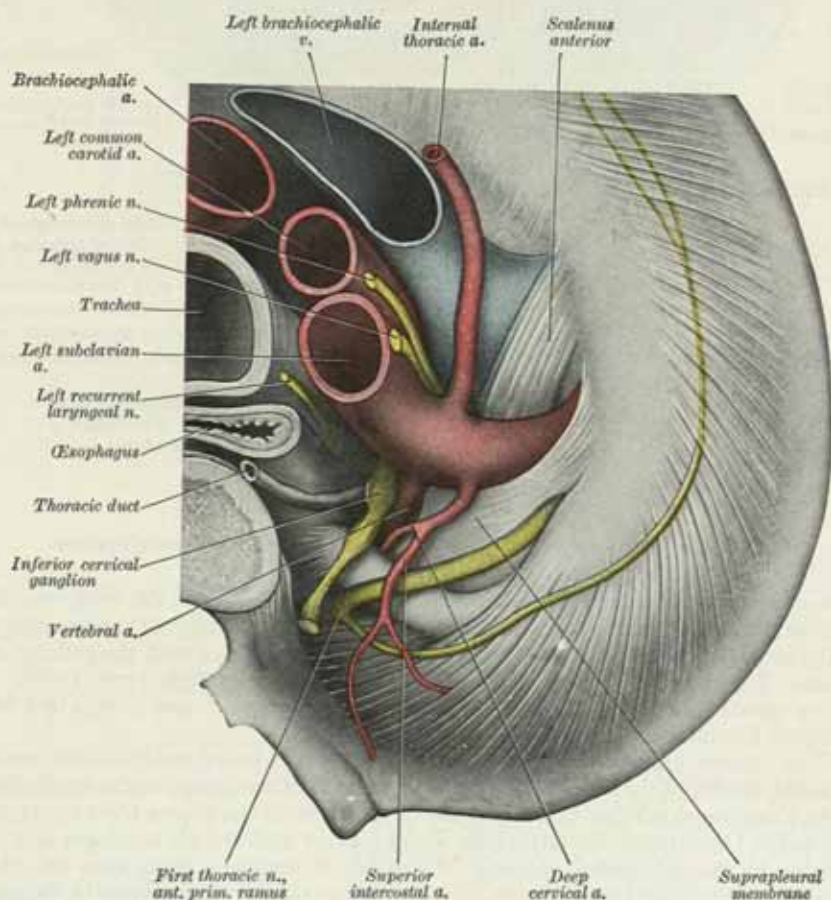
pleura. Above, the costal pleura is continuous with the cervical pleura at the inner margin of the first rib. Below, it is continuous with the diaphragmatic pleura along a line which may differ slightly on the two sides. On the right side this *costo-diaphragmatic line of reflection* of the pleura begins behind the xiphoid process, and runs downwards and backwards behind the seventh costal cartilage, and reaches the midaxillary line at the level of the tenth rib; from here the line ascends slightly, and crossing the twelfth rib, reaches the level of the upper border of the spine of the twelfth thoracic vertebra (fig. 1100). On the left side the line follows at first the ascending part of the sixth costal cartilage, and in the rest of its course may be slightly lower than that on the right side.

The *diaphragmatic pleura* is thin, and covers part of the upper surface of the corresponding side of the Diaphragm. The outer part of its circumference is the line described above, along which it is continuous with the costal pleura. Medially it is continuous with the mediastinal pleura along the line of attachment of the pericardium to the Diaphragm.

The *cervical pleura* or *dome of the pleura* is the continuation of the costal pleura

over the apex of the lung (fig. 1098). It extends from the inner border of the first rib medially and upwards to the apex of the lung, its summit reaching as high as the lower edge of the neck of the first rib; it then descends along the side of the trachea to become continuous with the mediastinal pleura. Owing to the obliquity of the first rib, the cervical pleura extends 3 or 4 cm. above the first costal cartilage, but does not rise above the level of the neck of the first rib. The cervical pleura is strengthened by a dome-like expansion of fascia, named the *suprapleural membrane*. It is attached in front to the inner border of the first rib and behind to the anterior border of the transverse process of the seventh cervical vertebra; it is covered and strengthened by a few spreading muscular fibres derived from the *Scaleni*. A muscle that is frequently present, called the *Scalenus minimus*, arises from the anterior border of the transverse process of the seventh cervical vertebra and is inserted into the inner border of the first rib, behind the groove for the subclavian artery, and into the dome of the pleura, which on contraction, it renders tense; some consider that the suprapleural membrane represents the spread-out tendon of this muscle. The cervical pleura (like the apex of the lung) reaches the level of the seventh cervical spine at a distance of 2.5 cm. from the median plane. It can be represented by a curved line drawn from the sternoclavicular joint to the junction of the medial and middle thirds of the clavicle, the summit of the curve being

FIG. 1097.—Structures in relation with the cervical pleura of the left side.
Seen from below.

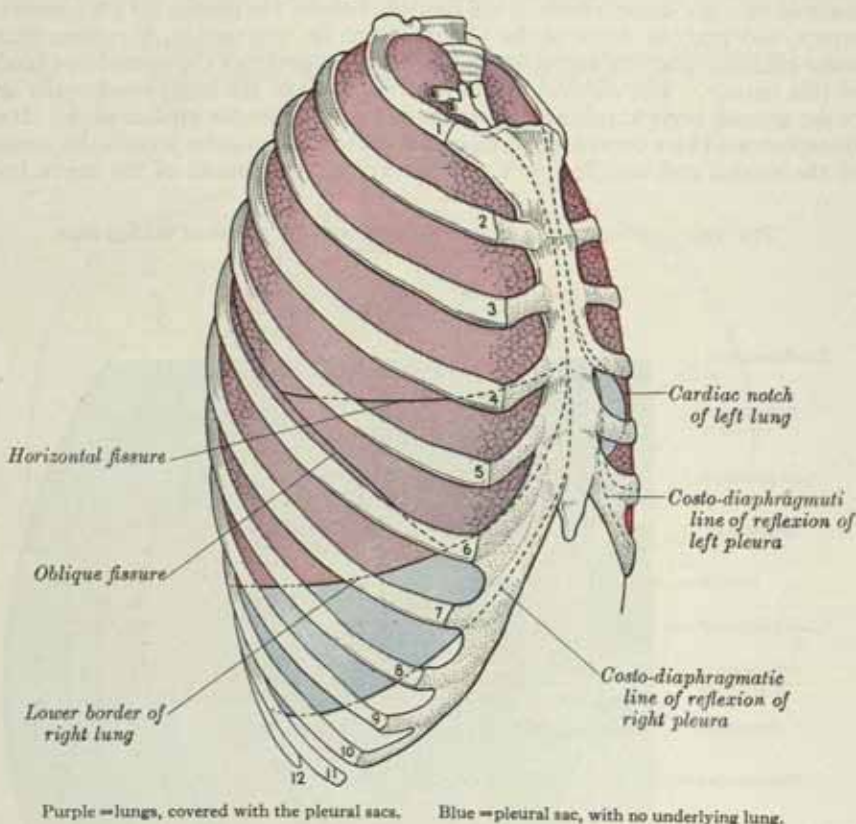


2.5 cm. above the clavicle. The subclavian artery, directed upwards and laterally, occupies a furrow a little below the summit of the cervical pleura. The relations of the cervical pleura are similar to those of the apex of the lung (see p. 1334, and fig. 1097).

The *mediastinal pleura* forms the lateral boundary of the interpleural space or

mediastinum (*see also* p. 1331). Above the root of the lung it is a continuous sheet between the sternum and the vertebral column. That of the right side is in contact with the right brachiocephalic vein, the upper part of the superior vena cava, the terminal part of the azygos vein, the right phrenic and right vagus nerves, the trachea and the œsophagus. That of the left side is in relation with the arch of the aorta, the left phrenic and left vagus nerves, the left brachiocephalic and superior intercostal veins, the left common carotid and subclavian arteries, the thoracic duct and the œsophagus. At the root of the lung the mediastinal pleura is carried laterally as a tube of serous membrane enclosing the structures of the lung-root and passing

FIG. 1098.—The relations of the pleuræ and lungs to the chest wall.
Right lateral aspect.

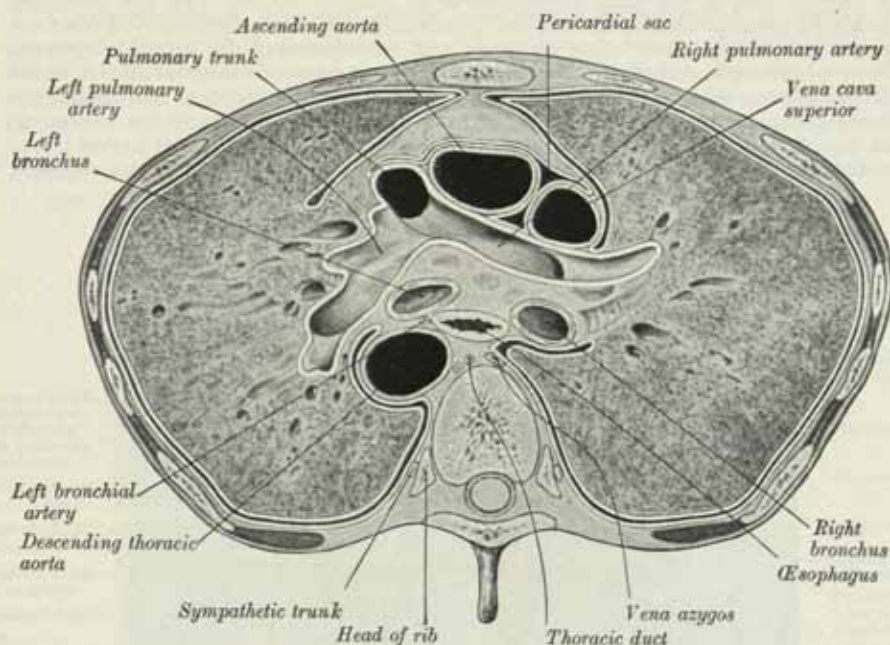


into continuity with the visceral or pulmonary pleura. Below the lung-root the mediastinal pleura extends as a double layer from the lateral edge of the œsophagus to the mediastinal surface of the lung, where it is continuous with the pulmonary pleura. This double layer is named the *pulmonary ligament* (figs. 1107, 1108). It is continuous above with the tube investing the lung-root; below it ends in a free falciform border.

The inferior limit of the pleura is on a considerably lower level than the corresponding border of the lung (figs. 1096, 1098), but does not extend to the attachment of the Diaphragm, so that below the line of reflexion of the pleura from the chest-wall to the Diaphragm, the latter is in direct contact with the rib cartilages and the muscles in the intercostal spaces. Moreover, in ordinary inspiration the thin inferior margin of the lung does not extend as low as the line of the pleural reflexion, with the result that the costal and diaphragmatic pleuræ are here in contact, the intervening narrow slit being termed the *costodiaphragmatic recess*. In quiet respiration the lower limit of the lung is about 5 cm. above the lower limit of the pleura. A similar condition exists behind the sternum and rib cartilages, where the anterior thin margin of the lung falls short of the line of pleural reflexion, and where the slit-like cavity between the two layers of pleura forms the *costomediastinal recess*.

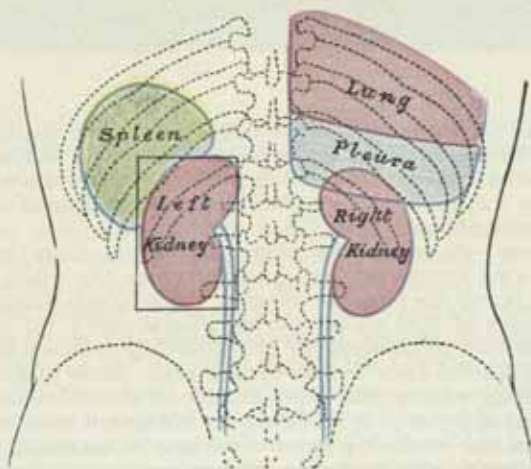
Structure.—The free surface of the pleura is smooth, and moistened by serous fluid. Like other serous membranes, it is covered by a single layer of flattened cells, united at their edges by cement-substance. These cells form a mesothelium, and rest

FIG. 1099.—A transverse section through the thorax at the level of the lower part of the fifth thoracic vertebra.



on a basement-membrane. Beneath the basement-membrane there are networks of yellow elastic and white fibres, imbedded in ground-substance which also contains connective tissue cells. The deeper layers of fibrous tissue in the pulmonary pleura are continuous with the connective tissue around and between the lobules of the lung. Blood-vessels, lymph vessels and nerves are distributed in the substance of the pleura.

FIG. 1100.—The lower limits of the lung and pleura, viewed from behind.

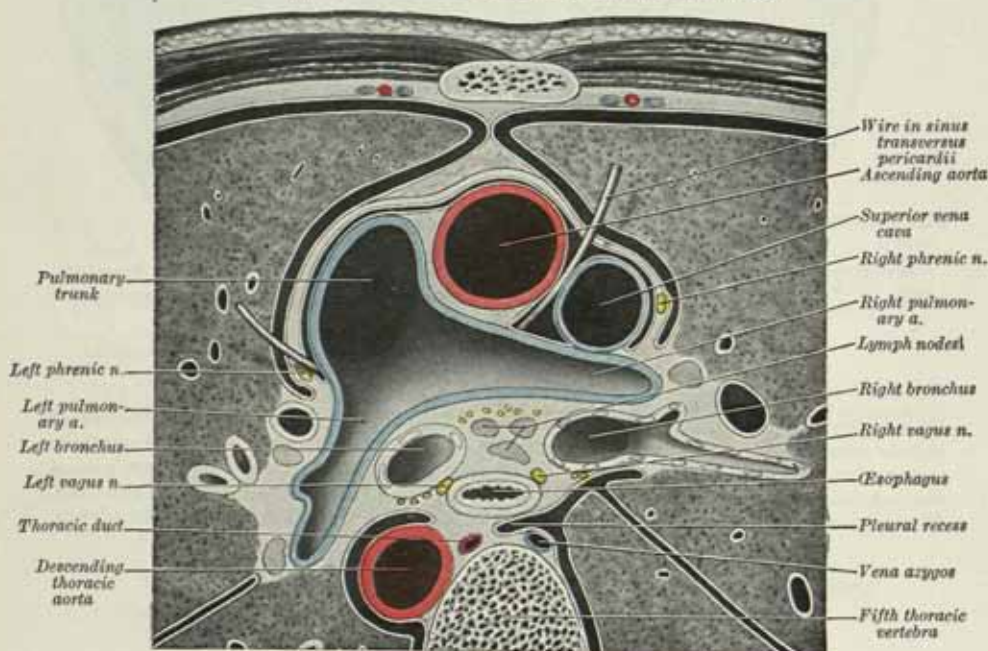


The lower portions of the lung and pleura are shown on the right side.

Vessels and Nerves.—The parietal and pulmonary layers of the pleura are respectively developed from the somatopleural and splanchnopleural layers of the lateral plate mesoderm (pp. 79, 202). Correlated with this origin, the parietal pleura

derives its arterial supply from somatic (body-wall) arteries (the intercostal, internal thoracic and musculophrenic), its veins join the systemic veins in the neighbouring parts of the chest-wall, its lymphatics also join those in the body-wall and drain into the intercostal, sternal, posterior mediastinal and diaphragmatic nodes, and its nerve-supply is derived from the spinal nerves supplying the muscles and skin of the body-wall (intercostal and phrenic nerves), whereas the pulmonary pleura, which is an integral part of the lung itself, derives its vascular supply from the bronchial vessels, its lymphatics join those of the lung, and its nerve-supply is derived from the sympathetic nerves innervating the lung and accompanying the bronchial vessels. Thus, whereas pain is elicited by the application of tactile or thermal stimuli to the parietal pleura, these do not form adequate stimuli when applied to the pulmonary pleura (compare the peritoneum, p. 1414). The costal pleura and the pleura on the peripheral part of the diaphragm are supplied by the intercostal nerves; the mediastinal pleura and the pleura on the central part of the diaphragm are supplied

FIG. 1101.—A transverse section through the mediastinum at the level of the upper part of the body of the fifth thoracic vertebra.



by the phrenic nerve. Irritation of the former parts of the pleura results in pain referred along the intercostal nerves to the chest or abdominal wall, whereas irritation of the latter parts results in pain referred to the lower part of the neck and over the shoulder (that is, to the area of skin supplied by the same segments of the spinal cord that give origin to the phrenic nerve, C 3, 4, 5).

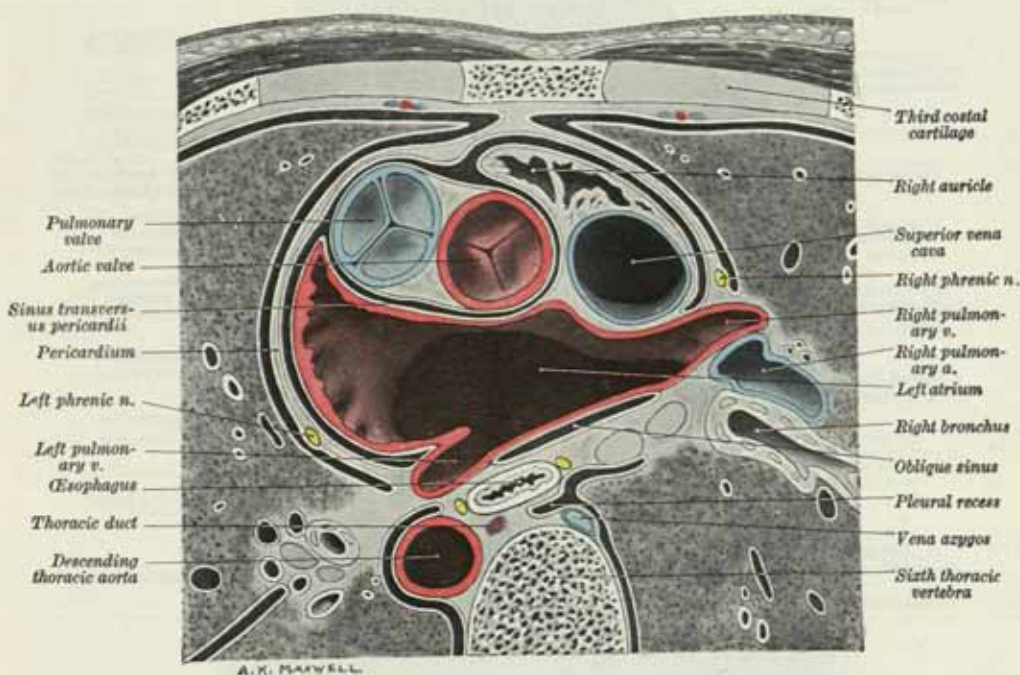
Applied Anatomy.—Normally the pulmonary pleura slides smoothly on the parietal pleura during respiration and does not cause any sound appreciable on auscultation; if however the pleura is inflamed, characteristic friction sounds can be heard. If an effusion of fluid occurs into the pleural cavity, the above sound disappears, and as the fluid accumulates the lung gradually collapses and the heart and mediastinum are displaced towards the opposite side. Entry of air into the pleural cavity (pneumothorax), whether caused accidentally by an external penetrating wound or by rupture of part of the lung, or produced as a therapeutic measure (e.g. to rest the lung in tuberculosis) also results in collapse of the lung, as the elastic tissue of the lung contracts. Normally this is prevented by the negative pressure in the pleural cavity and by the cohesion between the opposed parietal and pulmonary pleura. In operations on the kidney from the back, the relation of the costal pleura to the twelfth rib must be borne in mind. Usually the pleura crosses the rib at the lateral border of the Erector spinæ muscle, so that the posterior part of the rib lies above the lower line of the pleura (fig. 1100). If the last rib is too short to project beyond the Erector spinæ, the *eleventh* rib may be mistaken for the last when palpated in this position, and

an incision which is prolonged up to this level will wound the pleura. It is therefore important to determine whether the lowest palpable rib is the eleventh or twelfth by counting down from the second (at its junction with the sternal angle).

THE MEDIASTINUM

The **mediastinum**, strictly speaking, is the partition between the two lungs and therefore includes the mediastinal pleura of both sides, but it is more satisfactory to define it as the interval between the two pleural sacs. It extends from the sternum in front to the vertebral column behind (figs. 1101, 1102), and from the thoracic inlet above to the Diaphragm below. For purposes of description it is divided into

FIG. 1102.—A transverse section through the mediastinum at the level of the body of the sixth thoracic vertebra.



two parts, an *upper*, which is named the superior mediastinum, and a *lower*, which is subdivided into (a) the anterior mediastinum, in front of the pericardium, (b) the middle mediastinum, occupied by the pericardium and its contents, and (c) the posterior mediastinum, behind the pericardium.

The **superior mediastinum** (figs. 1092, 1094) lies between the manubrium sterni in front, and the upper four thoracic vertebrae behind. It is bounded below by the plane passing through the sternal angle in front, and the lower part of the body of the fourth thoracic vertebra behind; above, by the plane of the thoracic inlet, and laterally by the mediastinal pleurae. It contains the origins of the Sternohyoid and Sternothyroid and the lower ends of the Longus cervicis muscles; the aortic arch; the brachiocephalic, left common carotid and left subclavian arteries; the brachiocephalic veins and the upper half of the superior vena cava; the left superior intercostal vein; the vagus, cardiac, phrenic and left recurrent laryngeal nerves; the trachea, oesophagus and thoracic duct; the remains of the thymus, and the paratracheal, brachiocephalic and some of the tracheobronchial lymph nodes.

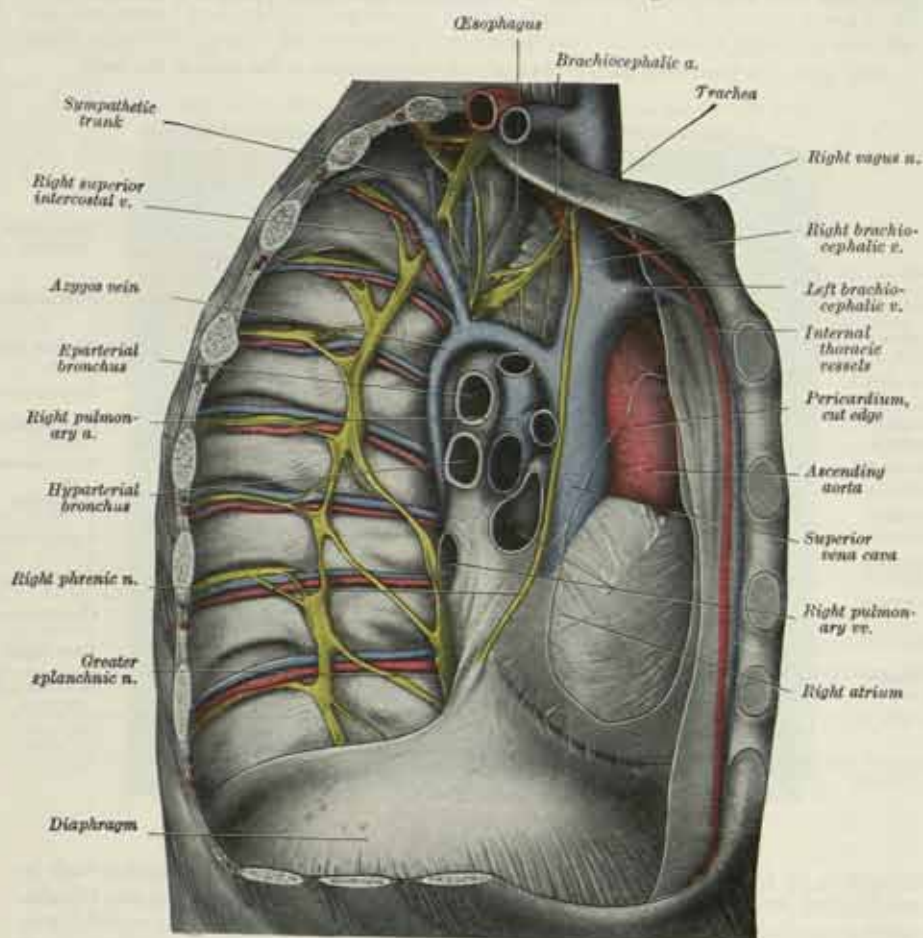
The **anterior mediastinum** lies between the body of the sternum in front and the pericardium behind (fig. 1101); above the level of the fourth costal cartilages, it is exceedingly narrow, owing to the close approximation of the two pleural sacs. It contains some loose areolar tissue, the sternopericardiac ligaments, two or three

lymph nodes and a few small mediastinal branches of the internal thoracic artery.

The **middle mediastinum** (figs. 1102, 1105) is the broadest of the subdivisions. It contains the heart enclosed in the pericardium, the ascending aorta, the lower half of the superior vena cava, the terminal part of the azygos vein, the bifurcation of the trachea, the two bronchi, the pulmonary trunk dividing into right and left pulmonary arteries, the right and left pulmonary veins, the phrenic nerves, the deep cardiac plexus and some tracheobronchial lymph nodes.

The **posterior mediastinum** (figs. 1101 to 1104) is bounded *in front* by the

FIG. 1103.—The mediastinum, from the right side.



A portion of the pericardial sac has been removed in order to expose the lateral surface of the right atrium.

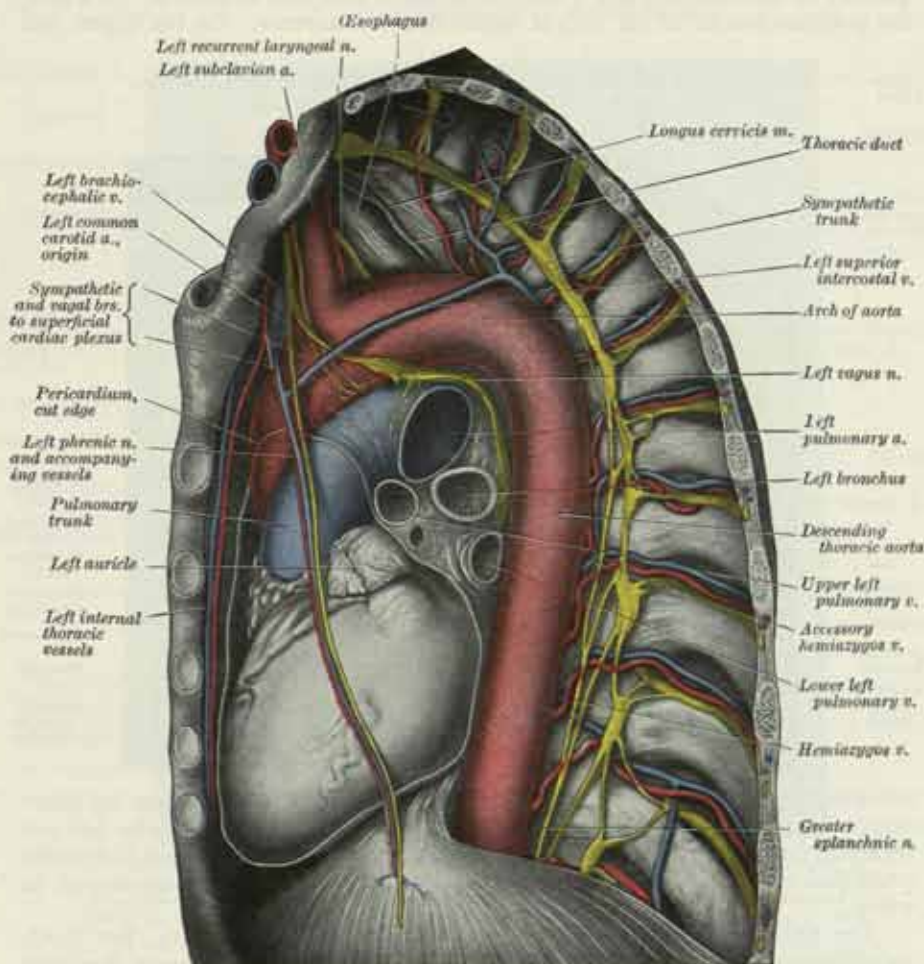
bifurcation of the trachea, the pulmonary vessels, the pericardium and by the posterior surface of the Diaphragm; *behind*, by the vertebral column from the lower border of the fourth to the twelfth thoracic vertebra; and *on each side* by the mediastinal pleura. It contains the descending thoracic aorta, the azygos and hemiazygos veins, the vagus and splanchnic nerves, the œsophagus, the thoracic duct, and the posterior mediastinal lymph nodes.

Radiology of the mediastinum (Pls. XIX, XX).—In anteroposterior radiographs of the chest (Pl. XIX), the heart and large blood-vessels form an opacity called the mediastinal shadow. Forming the left border of this shadow can be recognised, from above downwards, the left subclavian artery, the arch of the aorta ('the aortic knuckle'), the left auricle and the left ventricle. Immediately below the aortic arch, the infundibulum of the right ventricle or the pulmonary trunk may be recognisable on this border. On the right border of the shadow are

seen the right brachiocephalic vein, the superior vena cava, the right atrium and the thoracic part of the inferior vena cava. Enlargements or lateral displacements of any of the above structures accentuate the normal 'bulges' on the borders of the mediastinal shadow. On either side of the mediastinum, the opacities of the pulmonary vessels entering the lungs constitute the root or hilar shadows. In the upper part of the chest the translucent trachea is seen in the median plane.

In lateral or oblique radiographs (Pl. XX) the heart shadow lies above the

FIG. 1104.—The mediastinum, from the left side.



anterior part of the diaphragm. In front of it is 'the retrosternal space' (the anterior mediastinum), while behind it is 'the retrocardiac space' (posterior mediastinum) containing the œsophagus, rendered visible during the passage of a barium meal, and the descending thoracic aorta. Above the heart shadow, the translucent trachea and bronchi are recognisable, and the aortic arch and large vessels in the superior mediastinum produce faint shadows.

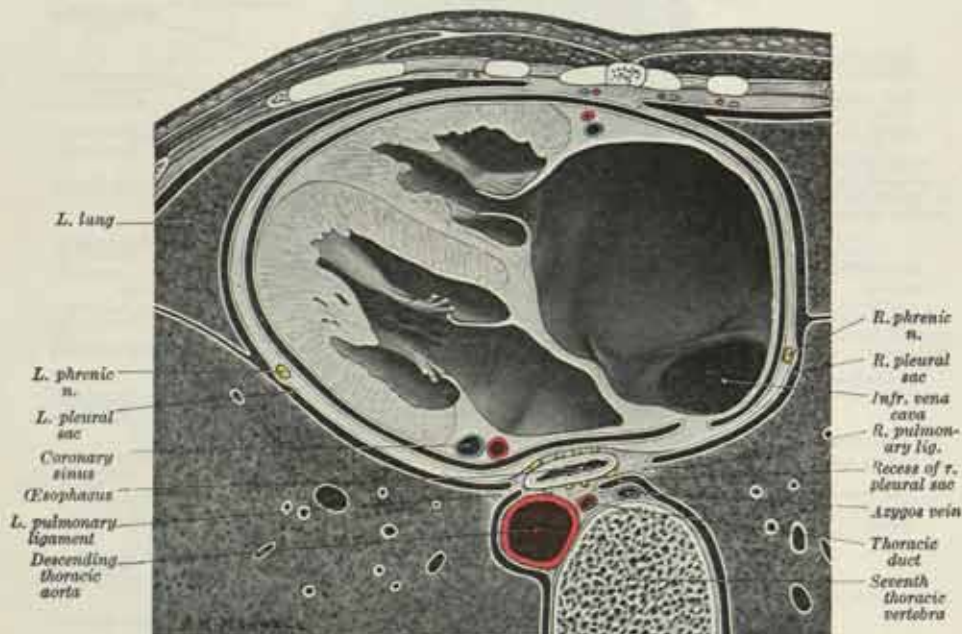
THE LUNGS (PULMONES)

The **lungs** are the essential organs of respiration; they are two in number, placed one on each side within the thorax, and separated from each other by the heart and the other contents of the mediastinum (fig. 1106). Except for its attachment to the heart and trachea by the root (and the pulmonary ligament), each lung lies freely in the corresponding pleural cavity. The substance of the lung is of a light, porous, spongy texture; it floats in water, and crepitates when handled,

owing to the presence of air in its alveoli; it is also highly elastic; hence the retracted state of the lungs when they are removed from the closed cavity of the thorax. The surface is smooth, shining, and marked out by fine dark intersecting lines into numerous polyhedral areas, indicating the lobules of the lung; each of these areas is crossed by numerous lighter lines.

At birth the lungs are rose pink in colour; in adult life the colour is a dark slaty-grey, mottled in patches; and as age advances, this mottling assumes a black colour. The colouring matter consists of granules of inhaled carbonaceous matter (dust) deposited in the areolar tissue near the surface of the lung; it increases in quantity as age advances, and is more abundant in men than in women. As a rule, the posterior border of the lung is darker than the anterior. On the upper, less

FIG. 1105.—A transverse section through the mediastinum at the level of the body of the seventh thoracic vertebra.



movable parts of the lungs, the surface pigmentation tends to lie opposite the intercostal spaces. The lungs of the fetus, or of the still-born child who has not breathed, differ from those of the child who has breathed in that they are firm to the touch (like the liver), do not crepitate when handled, and, containing no air, sink in water.

The right lung usually weighs about 625 gm., the left 567 gm., but much variation occurs, and it is also dependent on the amount of blood or serous fluid that they contain. The lungs are heavier in the male than in the female; their proportion to the body-weight is, in the former, as 1 to 37, in the latter as 1 to 43.

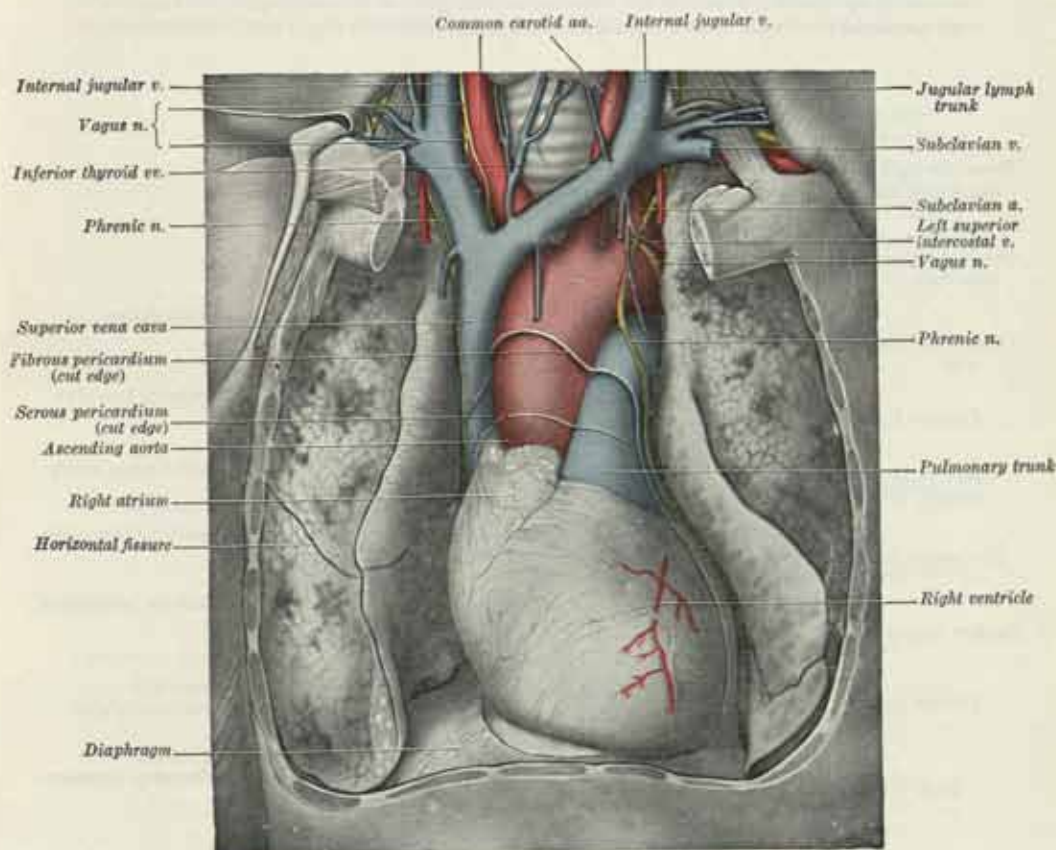
Each lung is conical in shape, and has an apex, a base, three borders and two surfaces.

The *apex*, which is rounded, lies in the plane of the thoracic inlet, in close contact with the cervical pleura. Owing to the obliquity of the inlet (p. 262), this part of the lung reaches from 3 cm. to 4 cm. above the level of the first costal cartilage, although it does not rise above the level of the neck of the rib. Its summit lies about 2.5 cm. above the medial third of the clavicle, and the apex is situated therefore in the root of the neck (fig. 1098). The cervical pleura intervenes between the apex of the lung and the suprapleural membrane (p. 1327), on which the subclavian artery arches upwards and laterally, producing a groove on the anterior surface of the apex just below its summit and separating it from the *Scalenus anterior*. Posteriorly the apex is related to the inferior cervical and first thoracic ganglia of the sympathetic trunk, the anterior primary ramus of the first thoracic nerve and the superior intercostal artery (fig. 1097). Laterally, it is related to the *Scalenus medius*; medially,

to the brachiocephalic artery, right brachiocephalic vein and trachea, on the right side, and to the left subclavian artery and left brachiocephalic vein, on the left side.

The *base* is semilunar in shape, and concave; it rests upon the convex surface of the Diaphragm, which separates the right lung from the right lobe of the liver, and the left lung from the left lobe of the liver, the fundus of the stomach and the spleen. Since the Diaphragm extends higher on the right side than on the left, the concavity on the base of the right lung is deeper than that on the left. Laterally

FIG. 1106.—A dissection to display the heart, great vessels and lungs in situ.



The sternum and the sternal ends of the costal cartilages, together with the parietal pleura on each side, have been excised, and the mediastinal pleura and parietal layer of the pericardium over the antero-superior surface of the heart have been removed. Both lungs have been retracted to expose the heart fully, and the epicardium has been dissected off the heart and the roots of the great vessels.

On the right side, the inferior cardiac branch of the vagus nerve descends between the brachiocephalic artery and the right brachiocephalic vein. On the left side, a communication descends from the left superior intercostal vein and crosses the aortic arch and the left pulmonary artery to become continuous with the oblique vein of the left atrium.

and behind, the base is bounded by a thin, sharp margin which projects for some distance into the costodiaphragmatic recess of the pleura.

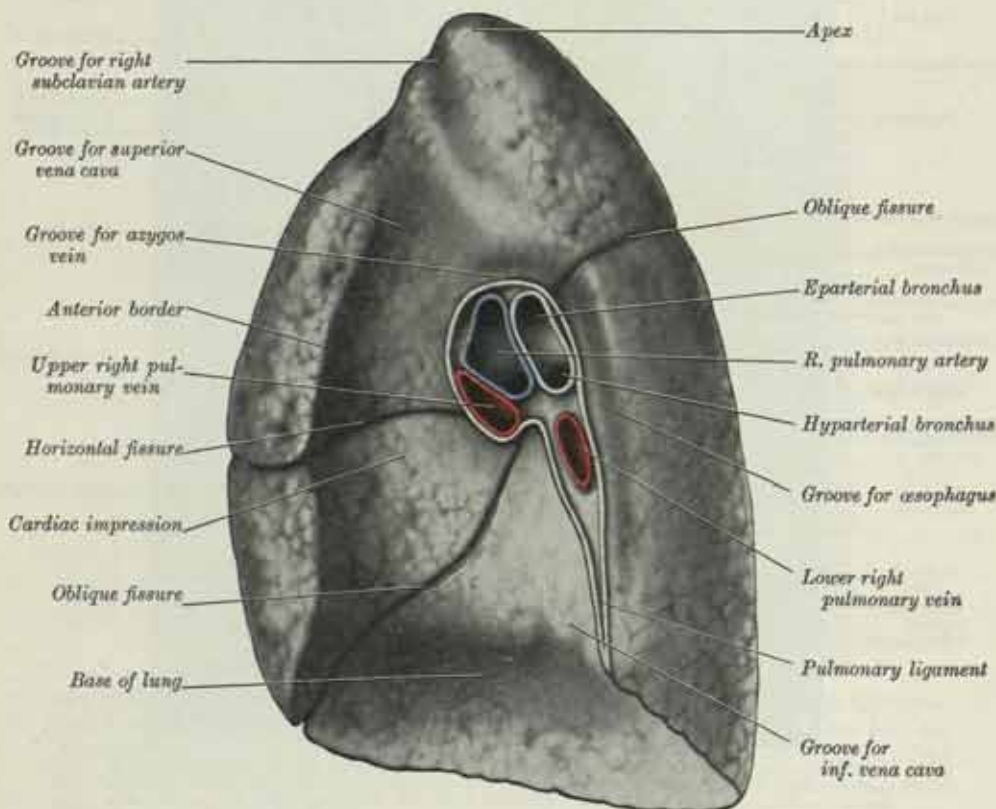
The *costal surface* is smooth, convex, of considerable extent, and corresponds to the form of the cavity of the chest, which is deeper behind than in front. It is in contact with the costal pleura, and exhibits, in specimens which have been hardened *in situ*, slight grooves corresponding with the overlying ribs.

The *medial surface* is divided into a posterior or *vertebral* part, and an anterior or *mediastinal* part. The vertebral part is in contact with the sides of the thoracic vertebrae and intervertebral discs, the posterior intercostal vessels and the splanchnic nerves. The mediastinal part exhibits a deep concavity, which accommodates the pericardium and is termed the *cardiac impression*; this concavity is larger and deeper on the left than on the right lung, because the heart projects more to the left than to the right side of the median plane. Above and behind this concavity there is a

somewhat triangular depression named the *hilus*, where the structures which form the root of the lung (p. 1338) enter and leave the viscus. These structures are invested by pleura, which extends downwards, below the hilus and behind the cardiac impression, and forms the pulmonary ligament.

Apart from these features, which are shared in common by both lungs, the markings on the mediastinal surface seen in specimens hardened *in situ* are different on the two sides. On the *right lung*, the cardiac impression is in relation with the anterior surface of the right auricle, the anterior and lateral (right) surfaces of the right atrium and a small part of the anterior surface of the right ventricle. It is continued upwards in front of the hilus as a wide groove which lodges the superior vena cava and the lower end of the right brachiocephalic vein (fig. 1107). Posteriorly

FIG. 1107.—The medial surface of the right lung.



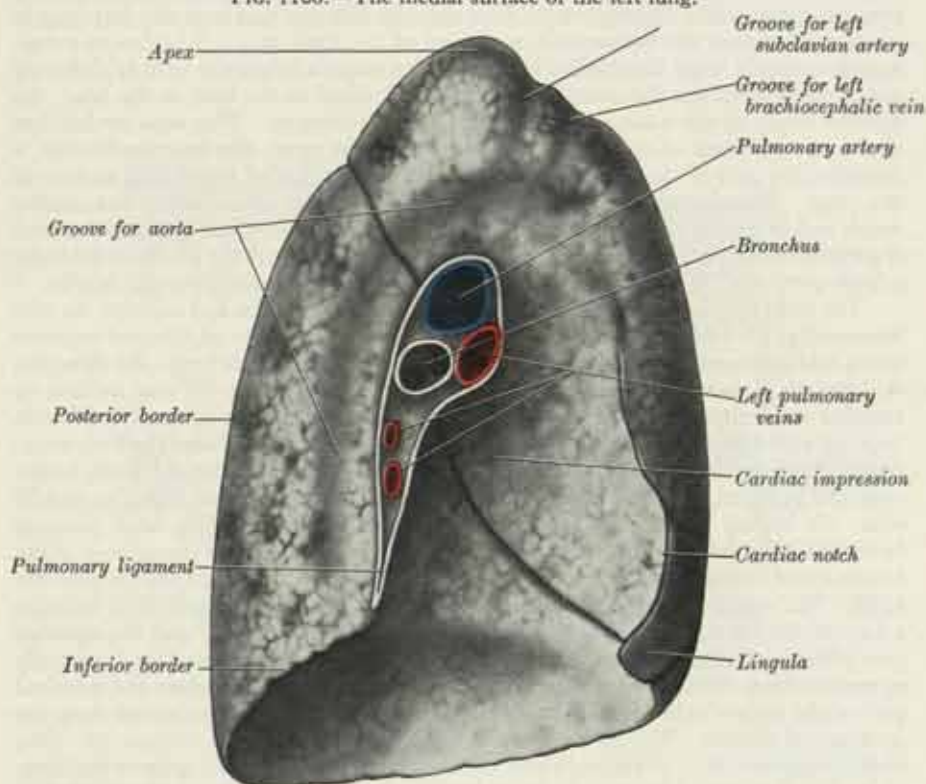
this groove is joined by a deep, narrow groove which arches forwards above the hilus and is caused by the azygos vein. The right edge of the œsophagus produces a shallow groove which runs vertically downwards behind the hilus and the pulmonary ligament. As it approaches the Diaphragm, the œsophagus inclines towards the left and passes away from the right lung. The œsophageal groove, therefore, does not extend to the lower limit of this surface. The postero-inferior corner of the cardiac impression is confluent with a short but wide notch which accommodates the thoracic part of the inferior vena cava. Between the apex and the groove for the azygos vein, the trachea and the right vagus nerve are in close relation to the lung, although there is no corresponding surface depression.

On the *left lung* (fig. 1108), the cardiac impression is in relation with the anterior and left surfaces of the left ventricle and left auricle, and the anterior surface of the infundibulum and adjoining part of the right ventricle. It is continued upwards in front of the hilus to accommodate the pulmonary trunk. A wide, deep groove arches backwards above the hilus and downwards behind it and the pulmonary ligament; it lodges the arch and the descending part of the aorta. Near the summit of its curve it is confluent with a narrower groove which ascends

towards the apex and is occupied by the left subclavian artery. Behind this groove and above the aortic groove, the lung is in contact with the thoracic duct and the left edge of the œsophagus. In front of the upper part of the groove for the left subclavian artery a faint groove is produced by the left brachiocephalic vein. Inferiorly, the left edge of the œsophagus may make a slight impression in front of the lower end of the pulmonary ligament.

The *inferior border* is thin and sharp where it separates the base from the costal surface and extends into the costodiaphragmatic recess; medially, where it divides the base from the mediastinal surface, it is blunt and rounded. It is represented, during quiet respiration, by a line drawn from the lower end of the anterior border to reach the eighth rib in the midaxillary line, where it lies nearly 10 cm. above the

FIG. 1108.—The medial surface of the left lung.



costal margin; the line is then continued medially and slightly upwards across the back to a point 2 cm. lateral to the tenth thoracic spine (fig. 1100). The *posterior border* separates the costal surface from the vertebral part of the medial surface, and corresponds to the medial margins of the heads of the ribs. It is not marked by any recognisable ridge or line. The so-called 'thick, rounded posterior border' comprises the adjoining parts of the costal and vertebral surfaces.

The *anterior border* is thin and sharp, and overlaps the front of the pericardium; that of the *right lung* corresponds very closely to the costomediastinal line of pleural reflection and is almost vertical; that of the *left* corresponds to the costomediastinal line of pleural reflection in its upper part, but below the level of the fourth costal cartilage it presents a notch of variable size, named the *cardiac notch*. The margin of this notch passes laterally for 3.5 cm. before curving downwards and medially to reach the sixth costal cartilage 4 cm. from the median plane. It thus falls considerably short of the recessed part of the line of pleural reflection (fig. 1096), leaving the pericardium in this situation covered only with a double layer of pleura. (See *Area of superficial cardiac dullness*, p. 717.)

The fissures and lobes of the lungs.—The *left lung* is divided into a superior and an inferior lobe by an *oblique fissure* (fig. 1108), which extends from the costal

to the medial surface of the lung both above and below the hilus. As seen on the surface, this fissure begins on the medial surface of the lung at the upper and posterior part of the hilus, and runs backwards and upwards to the posterior border, which it crosses at a point about 6 cm. below the apex. It then extends downwards and forwards over the costal surface (fig. 1096), reaching the lower border a little behind its anterior extremity. Its further course can be followed upwards and backwards across the mediastinal surface as far as the lower part of the hilus. On the posterior border of the lung the oblique fissure lies opposite the interval between the spines of the third and fourth thoracic vertebræ (about 2 cm. from the median plane), but it may be either above or below this level. Traced downwards and forwards across the costal surface of the lung, the fissure crosses the fifth intercostal space (in or near the midaxillary line) and follows the fifth intercostal space until it intersects the inferior border of the lung close to, or just below the sixth costochondral junction (7.5 cm. from the median plane). As a rule the oblique fissure of the left lung is more vertical than the corresponding fissure of the right lung. The fissure corresponds roughly with the medial border of the scapula when the arm is abducted above the level of the shoulder, as by placing the hand on the back of the head, the inferior angle of the bone moving outwards and forwards. The *superior lobe* lies above and in front of this fissure, and includes the apex, the anterior border, a considerable part of the costal surface and the greater part of the medial surface of the lung. A small projection is sometimes present at the lower part of the cardiac notch and is termed the *lingula* of the lung. The *inferior lobe*, the larger of the two, is situated below and behind the fissure, and comprises almost the whole of the base, a large portion of the costal surface, and the greater part of the posterior border.

The *right lung* is divided into three lobes, superior, middle and inferior, by two fissures (fig. 1107). One of these separates the inferior from the middle and superior lobes, and corresponds closely with the oblique fissure in the left lung. Its direction is, however, less vertical, and it cuts the lower border about 7.5 cm. behind its anterior extremity. On the posterior border it lies opposite the spine of the fourth thoracic vertebra or at a slightly lower level. As it descends it crosses the fifth intercostal space and then follows the general line of the sixth rib to the sixth costochondral junction. A short *horizontal fissure* separates the superior from the middle lobe. It begins in the oblique fissure near the midaxillary line, and, running horizontally forwards, cuts the anterior border on a level with the sternal end of the fourth costal cartilage; on the mediastinal surface it may be traced backwards to the hilus. The *middle lobe* of the right lung is small and wedge-shaped, and includes a part of the costal surface, the lower part of the anterior border and the anterior part of the base of the lung. Sometimes the medial part of the upper lobe is partially separated from the rest by a fissure of variable depth which contains the terminal part of the azygos vein enclosed in the free margin of a mesentery derived from the mediastinal pleura. The portion of the right lung so defined is termed the 'lobe of the azygos vein'. It varies in size and sometimes includes the apex of the lung. It is always supplied by one or more branches of the apical bronchus.* Radiographically, a pleural effusion may be found limited to the azygos fissure.

Since the Diaphragm rises higher on the right side in order to accommodate the liver, the right lung is shorter (by 2.5 cm.) than the left, but, owing to the projection of the heart to the left side, it is broader and its total capacity and weight are greater than those of the left lung.

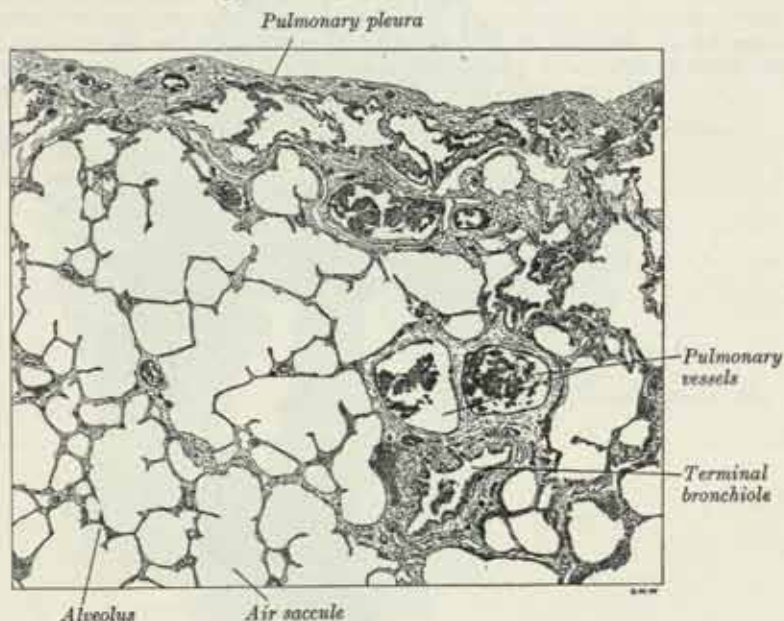
The roots of the lungs (figs. 1103, 1104).—The root of the lung connects the medial surface to the heart and the trachea and is formed by the structures which enter or emerge at the hilus. It comprises the bronchus, the pulmonary artery, the two pulmonary veins, the bronchial arteries and veins, the pulmonary plexuses of nerves, lymph vessels, bronchopulmonary lymph nodes and areolar tissue, all of which are enveloped by pleura. The roots of the lungs lie opposite the bodies of the fifth, sixth and seventh thoracic vertebræ. That of the right lung lies behind the superior vena cava and part of the right atrium of the heart, and below the terminal part of the azygos vein. That of the left lung is below the aortic arch and in front of the descending thoracic aorta. The following relations are common to the two lung-roots, viz.: in front, the phrenic nerve, the pericardiophrenic artery and vein, and the anterior pulmonary plexus; behind, the vagus nerve and posterior pulmonary plexus; below, the pulmonary ligament.

* R. C. Brock, *Guy's Hosp. Rep.*, 93, 1944.

The chief structures composing the root of each lung are arranged in a similar manner from before backwards on both sides, viz. : the upper of the two pulmonary veins in front ; the pulmonary artery in the middle ; and the bronchus behind, with the bronchial vessels on its posterior aspect. Their arrangement differs from above downwards on the two sides ; on the right side their position is—eparterial bronchus, pulmonary artery, hyparterial bronchus, lower pulmonary vein ; but on the left side their position is—pulmonary artery, bronchus, lower pulmonary vein. The lower of the two pulmonary veins is situated below the bronchus, at the lowest part of the hilus (figs. 1107, 1108).

All parts of the lungs do not move equally in respiration. The region near the root hardly moves at all, while the middle region of the lungs moves very slightly in quiet respiration. The superficial parts of the lungs expand most, but the mediastinal surface, the posterior border and the apical region do not move to the same extent owing to the less movable structures related to them. The diaphragmatic

FIG. 1109.—A section showing the structure of the adult human lung. Drawn from a photomicrograph. $\times \bar{e}$ 30.



and costomediastinal regions undergo most expansion of all. (See "Movements of Respiration", p. 588.)

Structure (figs. 1109, 1110, 1111).—The lungs are composed of a serous coat, a subserous areolar tissue, and the pulmonary substance.

The *serous coat* is the pulmonary pleura (p. 1325) ; it is thin, transparent, inseparably connected with the lung substance, and invests the entire organ as far as the root.

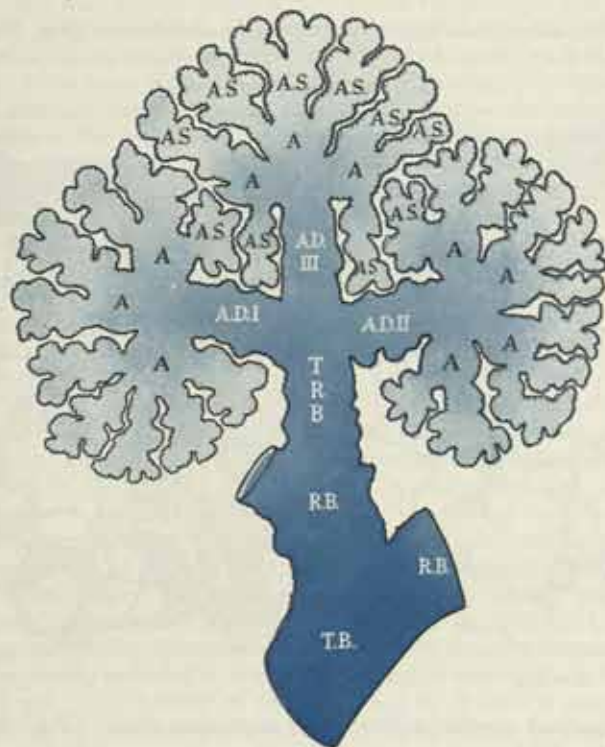
The *subserous areolar tissue* contains a large proportion of elastic fibres ; it invests the entire surface of the lung and extends inwards between the lobules.

The *pulmonary substance* is composed of lobules, which although closely connected by interlobular areolar tissue, are quite distinct from one another, and in the fœtus may be teased apart without much difficulty. The lobules vary in size ; those on the surface are large and of pyramidal form with the bases turned towards the surface ; those in the interior are smaller, and of various forms. Each lobule is composed of a terminal bronchiole and its air-cells, and of the ramifications of the pulmonary and bronchial vessels, lymph vessels, and nerves ; all of these structures being connected together by areolar tissue.

The bronchi divide and subdivide in the lung, but they run in the interstitial tissue and are separated from the respiratory part proper of the lung by fibro-areolar tissue. The larger branches have an outer fibrous coat containing mucous glands and irregularly disposed plates of hyaline cartilage ; the latter diminish in number and size in the smaller branches. Internal to this coat is a layer of circularly disposed smooth muscle fibres (the *bronchial muscle*), which is not in the form of a continuous coat as in the wall of the gut but is arranged as a lattice-like network. The mucous mem-

brane contains some lymphoid tissue, the ducts of the mucous glands and numerous elastic fibres running for the main part longitudinally; it is lined by ciliated columnar epithelium set on a basement membrane. The smaller branches of the bronchi are called bronchioles. The terminal bronchioles are about 0.2 mm. in diameter and are called *respiratory bronchioles*. These form the first part of the respiratory lobules of the lung and from their walls project some alveoli. The respiratory bronchioles contain no cartilage in their walls and the lining epithelium is cubical and non-ciliated. Each respiratory bronchiole divides into a number (two to eleven) of *alveolar ducts*, which are tortuous and branch, the terminal branches leading into a number of expanded passages called *atria*, each of these in its turn leading into a terminal *air saccule* (fig. 1110). The walls of the alveolar ducts, atria and air saccules are studded with extremely thin-walled *pulmonary alveoli* which project from their

FIG. 1110.—A diagram showing a terminal bronchiole, dividing into two respiratory bronchioles, from one of which a terminal respiratory bronchiole is shown giving origin to three alveolar ducts, with their atria and air saccules. (After W. S. Miller).



T.B. = Terminal bronchiole.

R.B. = Respiratory bronchiole.

T.R.B. = Terminal respiratory bronchiole.

A.D. I, II and III = Alveolar ducts.

A = Atrium.

A.S. = Air saccule.

surfaces, and all these passages are lined by simple flat epithelium. The alveolar ducts contain some muscle in their coats, most marked at the entrances to the atria, but the muscular and fibrous coats of the larger tubes are absent from the atria and air saccules. Elastic fibres, however, form a network in the walls of all these passages, including the alveoli. The alveoli are intimately related by their outer surfaces to the pulmonary capillary plexus. There are conflicting opinions on the nature of the elements that separate the air in the alveoli from the blood stream, some maintaining that the air and blood are separated by both capillary endothelium and alveolar epithelium, others that only capillary endothelium forms the barrier (the alveolar epithelial cells not forming a complete lining to the alveoli), and yet others that only alveolar epithelium separates them (the capillary endothelium being deficient). The difficulty in histological interpretation may partly be due to the fact that the living alveolar epithelial cells are in part extremely flattened to form thin membrane-like flanges on the capillary walls and these may become retracted in fixed preparations, thus leaving parts of the capillary walls apparently bare. Histochemical and electron microscope studies* reveal that both the alveoli and the adjacent capillaries are lined by a continuous layer of exceedingly thin epithelium (0.2 μ or less thick), and that be-

* See F.N. Low, *Anat. Record.*, 1953, **117**, 241; F.D. Bertalanffy and C. P. Leblond, *Lancet*, 1955, **ii**, 1365.

tween these two epithelial layers are interposed two basement membranes (each less than 0.1μ thick), which in places are fused. Many of the alveolar cells are amoeboid and phagocytic; dust particles and other debris are engulfed and the cells migrate to the bronchioles, whence by ciliary action and finally coughing up they are expelled.

The respiratory bronchiole and its alveolar ducts, atria and air saccules, with the alveoli related to them, constitute a pulmonary unit; these units collectively form the respiratory part proper of the lung.

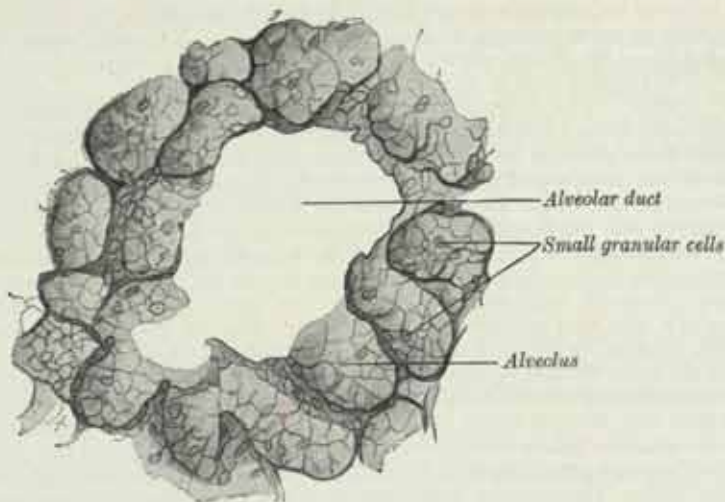
During expansion of the lung in inspiration, the elastic tissue is stretched and the bronchial muscle is relaxed; in expiration, the shortening and narrowing of the air passages are associated with recoil of the elastic fibres and contraction of the bronchial muscle.

The foetal lung resembles a gland in that the alveoli have small lumina and are lined with cubical epithelium. After the first respiration the alveoli become distended and the epithelium takes on the characters described above.

Vessels and Nerves.—The *pulmonary artery* conveys the deoxygenated blood to the lungs; it divides into branches which accompany the bronchial tubes and lie for the main part on their dorso-lateral aspects. They end in a dense capillary network in the walls of the air saccules and alveoli. The arteries of neighbouring lobules are independent of one another.

The *pulmonary capillaries* form plexuses which lie immediately beneath the lining epithelium, in the walls and septa of the alveoli and of the air saccules. In the septa between the alveoli the capillary network forms a single layer, the meshes of which are smaller than the vessels themselves; their walls are also exceedingly thin.

FIG. 1111.—A section through the lung of a kitten. Silver preparation. $\times 250$.



The *pulmonary veins*, two from each lung, arise from the pulmonary capillaries, the radicles coalescing into larger branches which run through the substance of the lung, independently of the pulmonary arteries and bronchi. After communicating freely with other branches they form large vessels, which ultimately come into relation with the arteries and bronchial tubes, and accompany them to the hilus of the lung, the artery usually being dorso-lateral, and the vein ventri-medial, to the bronchus. Finally, they open into the left atrium of the heart, conveying oxygenated blood to be distributed to all parts of the body by the left ventricle.

Whereas in the region of the hilus of the lung the pulmonary arteries and veins closely accompany the main divisions of the bronchi, when traced peripherally the arteries and veins assume different relationships to the bronchopulmonary segments (pp. 1321-1324). In general, the centrally placed bronchus and its branches supplying a bronchopulmonary segment are accompanied by branches of the pulmonary arteries, whereas the branches of the pulmonary veins run between bronchopulmonary segments, so that each venous branch drains several adjacent segments and each segment is drained by several veins. Some of the veins also lie beneath the visceral pleura, including that in the interlobar fissures of the lung. Thus a bronchopulmonary segment of the lung is not a bronchovascular unit in the sense of having its individual bronchus, artery and vein. In surgical resection of bronchopulmonary segments, it is to be noted that the planes between adjacent segments are not avascular, but are crossed by pulmonary veins and sometimes by branches of pulmonary arteries. There is considerable variation in the above pattern of the bronchi, arteries and veins, the

veins being more variable than the arteries, and the arteries more variable than the bronchi.*

The *bronchial arteries* supply blood for the nutrition of the lung; they are derived from the descending thoracic aorta or from the upper posterior (aortic) intercostal arteries, and, accompanying the bronchial tubes, are distributed to the bronchial glands and upon the walls of the larger bronchial tubes and pulmonary vessels. Those supplying the bronchial tubes form, in the muscular coat, a capillary plexus from which branches are given off to form a second plexus in the mucous coat; this plexus communicates with branches of the pulmonary artery, and empties itself into the pulmonary veins. Others are distributed in the interlobular areolar tissue, and end partly in the deep, partly in the superficial, bronchial veins. Lastly, some ramify upon the surface of the lung, beneath the pleura, where they form a capillary network. The bronchial arteries supply the walls of the air passages only as far as the respiratory bronchioles. They anastomose with branches of the pulmonary arteries in the walls of the smaller bronchi and in the visceral pleura. In addition to the main bronchial arteries, smaller branches arise from the descending thoracic aorta; one of these may pass in the pulmonary ligament and cause bleeding during surgical removal of the lower lobe.

The *bronchial veins* form two distinct systems.† The deep bronchial veins commence as a network in the intrapulmonary bronchioles and communicate freely with the pulmonary veins; they eventually join to form a single trunk which ends in a main pulmonary vein or in the left atrium. The superficial bronchial veins drain the extrapulmonary bronchi, the visceral pleura and the hilar lymph nodes; they also communicate with the pulmonary veins and end, on the right side in the azygos vein, and on the left in the left superior intercostal vein or the accessory hemiazygos vein. The bronchial veins do not receive all the blood conveyed to the lungs by the bronchial arteries as some passes into the pulmonary veins. The main bronchial arteries and veins lie on the dorsal surface of the extrapulmonary bronchi.

The *lymph vessels* of the lungs are described on p. 912.

Nerves.—The lungs are supplied from the anterior and posterior pulmonary plexuses, formed chiefly by branches from the sympathetic and vagus. The filaments from these plexuses accompany the bronchial tubes, supplying efferent fibres to the bronchial muscle and afferent fibres to the bronchial mucous membrane and to the alveoli of the lung. Small ganglia are found upon these nerves. It is generally believed that the bronchoconstrictors are supplied by the vagus (p. 1216).

Radiology (Pls. I, XIX).—The trachea, because of its contained air, is more radio-translucent than the neighbouring tissues and is therefore seen in lateral and anteroposterior radiographs of the neck and upper thorax as a dark area in negatives (or as a light area in positive prints; Pl. I). For the same reason the lungs appear as dark areas in the chest on either side of the central mediastinal opacity; the lung areas are darker at the end of inspiration and in a diseased condition in which the alveoli are permanently distended (emphysema), while they are more opaque in conditions which reduce the amount of air in them (e.g. pneumonia). The dark lung areas are not homogeneous but have superimposed on them the white shadows of the pulmonary blood-vessels extending from the hilus of the lung and branching into the lung areas,‡ (Pl. XIX). These white branching shadows are sometimes mistaken for bronchi, but the latter (because of their contained air) obviously appear as darker areas. Where a blood-vessel is seen end-on, it appears as a homogeneous white circle (Pl. XIX); where a bronchus is seen end-on, it appears as a dark circle surrounded by a white line (the latter representing the wall of the bronchus). Lymph nodes at the hilus of the lungs, if enlarged or calcified, appear as mottled areas near the mediastinum. The shape of the lumen of the bronchi and bronchioles can be rendered plainly visible by injecting lipiodol (a radio-opaque iodised oil) through the trachea. An effusion of fluid into the pleural cavity appears as an opacity in chest radiographs.

THE DIGESTIVE SYSTEM

The digestive system comprises all the organs which are concerned in the trituration, deglutition and digestion of food and in the elimination from the body of the unabsorbed and unabsorbable constituents. It consists of the digestive tube and certain accessory organs.

* For details consult the following. E. A. Boyden, *Segmental Anatomy of the Lungs: A Study of the Patterns of the Segmental Bronchi and Related Pulmonary Vessels*, 1955, Blakiston, New York; and *Diseases of the Chest*, 1949, 15, 657; also A. B. Appleton, *Lancet*, 1944, ii, 592; and *J. Anat., Lond.*, 1945, 79, 97.

† P. Marchand, J. C. Gilroy and V. H. Wilson, *Thorax*, 5, 207-221, 1950.

‡ T. Lodge, *Brit. J. Radiology*, 19, 1946.

The **digestive tube** (alimentary canal), about 9 metres long (*see footnote, p. 1423*), extends from the mouth to the anus, and is lined almost throughout by mucous membrane. It consists of the following parts: it commences at the *mouth*, where provision is made for the mechanical division of the food [*mastication*], and for its admixture with a fluid secreted by the salivary glands [*insalivation*]; it is conveyed by the organs of deglutition, termed the *pharynx* and the *œsophagus*, into the *stomach*, where the first stages of the digestive process take place; from the stomach it is passed into the *small intestine*, where the process of digestion is continued and many of the resulting products are absorbed into the blood- and lymph-vessels. Finally the small intestine ends in the *large intestine*, which reaches the surface of the body at the *anus*.

The **accessory organs** are the *teeth*, which break up and triturate the food in the process of mastication; the three pairs of *salivary glands*—the *parotid*, *submandibular* and *sublingual*—the secretion from which mixes with the food in the mouth; the *liver* and the *pancreas*, two large glands in the abdomen, the secretions of which take part in the process of digestion. In addition, it is convenient to describe the *peritoneum*—a serous membrane which lines the abdominal and pelvic cavities and invests the abdominal and pelvic viscera—in the same section with the abdominal part of the alimentary canal.

THE MOUTH CAVITY [CAVUM ORIS]

The **cavity of the mouth** consists of an outer, smaller portion, termed the vestibule, and an inner, larger part, termed the mouth cavity proper.

The *vestibule of the mouth* is a slit-like space, bounded externally by the lips and cheeks; internally, by the gums and teeth (fig. 1112). It communicates with the exterior by the *oral fissure*. Above and below, it is limited by the reflection of the mucous membrane from the lips and cheeks to the gums. When the jaws are closed it communicates with the mouth cavity proper by an aperture behind the wisdom teeth on each side, and by narrow clefts between opposing teeth. On the inner surface of the cheek, opposite the crown of the second upper molar tooth, a small papilla marks the opening of the duct of the parotid salivary gland.

The *mouth cavity proper* (figs. 1144, 1145) is bounded laterally and in front by the alveolar arches, the teeth and the gums; behind, it communicates with the pharynx by a constricted aperture termed the *oropharyngeal isthmus* (isthmus of the fauces *). Its roof consists of the hard palate and soft palate, while the greater part of the floor is formed by the anterior two-thirds of the tongue, the remainder by the reflection of the mucous membrane from the sides and under surface of the tongue to the gum on the inner surface of the mandible. In the median plane a crescentic fold of mucous membrane, named the *frenulum linguæ*, connects the under surface of the anterior part of the tongue to the floor of the mouth. On each side of the lower end of the frenulum there is a small elevation, termed the *sublingual papilla*, which bears on its surface the orifice of the duct of the submandibular salivary gland. From this papilla a ridge extends laterally and backwards in the mucous membrane of the floor of the mouth; it is produced by the underlying sublingual salivary gland and is termed the *sublingual fold*. The minute openings of the ducts of this gland are situated on the edge of the fold.

The *mucous membrane* lining the mouth is continuous with the skin at the free margins of the lips, and with the mucous lining of the pharynx at the oropharyngeal isthmus; it is of a rose pink tinge during life, and is very thick where it overlies the hard parts bounding the cavity. It is covered with stratified squamous epithelium, the superficial layers of which, unlike those of the skin, do not become cornified under normal conditions.

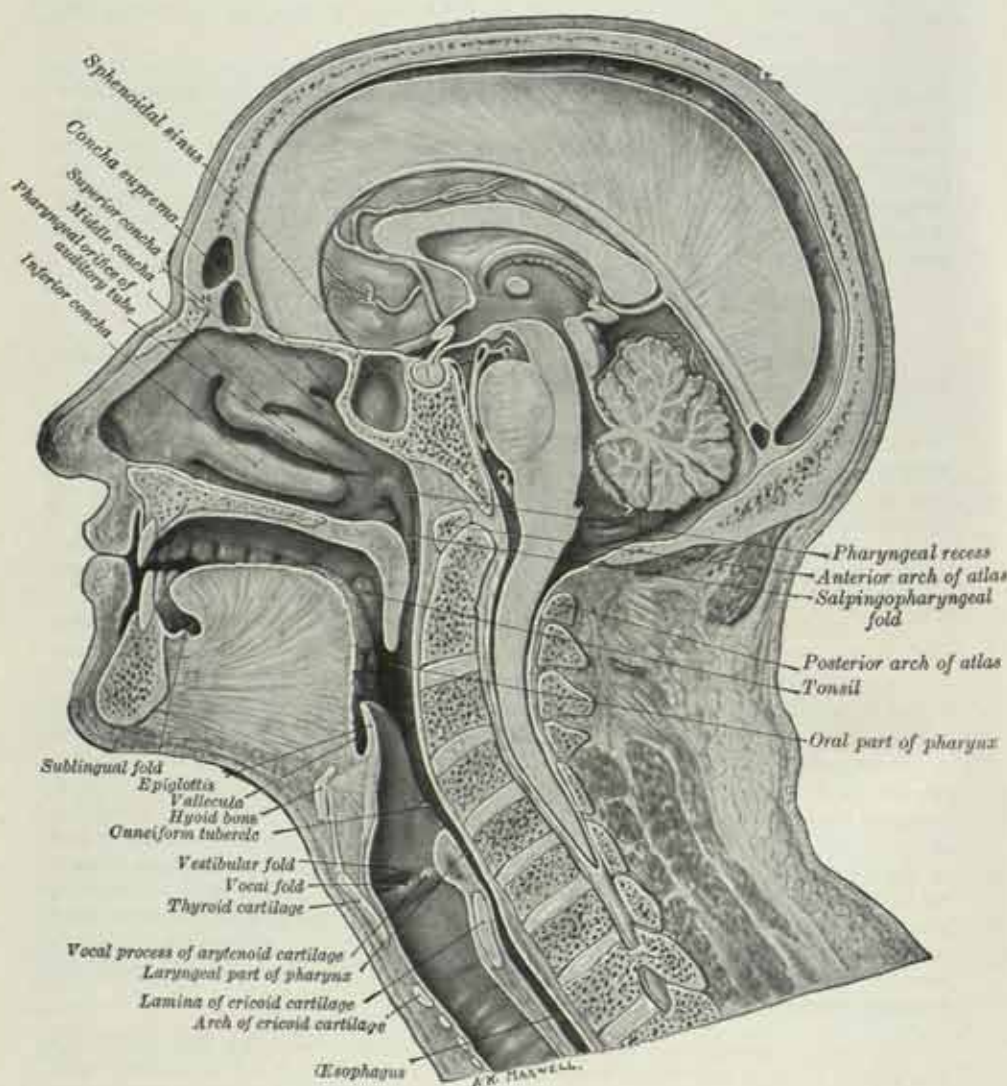
The *lymph vessels* of the mouth are described on p. 889.

The **lips** are two fleshy folds which surround the orifice of the mouth. They are formed externally of skin and internally of mucous membrane, and these two layers enclose the Orbicularis oris muscle, the labial vessels, some nerves, areolar tissue, and numerous small labial salivary glands. The junction of the upper with the

* These two terms are not quite synonymous, as the oropharyngeal isthmus is restricted to the interval between the palatoglossal arches, whereas the isthmus of the fauces is the region of the oral part of the pharynx bounded on either side by the triangular interval between the palatoglossal and palatopharyngeal arches.

lower lip (the *oral fissure*) lies opposite the cutting edges of the upper incisor teeth and forms, on each side, the *labial commissure*, which bounds the *angle of the mouth*; the latter usually lies just in front of the first premolar tooth. The middle part of the outer surface of the upper lip is marked by a shallow vertical groove named the *philtrum*; it ends below in a slight prominence and is limited on each side by a ridge. The inner surface of each lip is connected in the median plane to the corre-

FIG. 1112.—A median sagittal section through the head and neck.



Note.—Where it divides the skull and the brain, the section passes slightly to the left of the median plane, but below that level, it passes slightly to the right of the median plane.

sponding gum by a fold of mucous membrane, termed the *frenulum*—that of the upper lip being the larger.

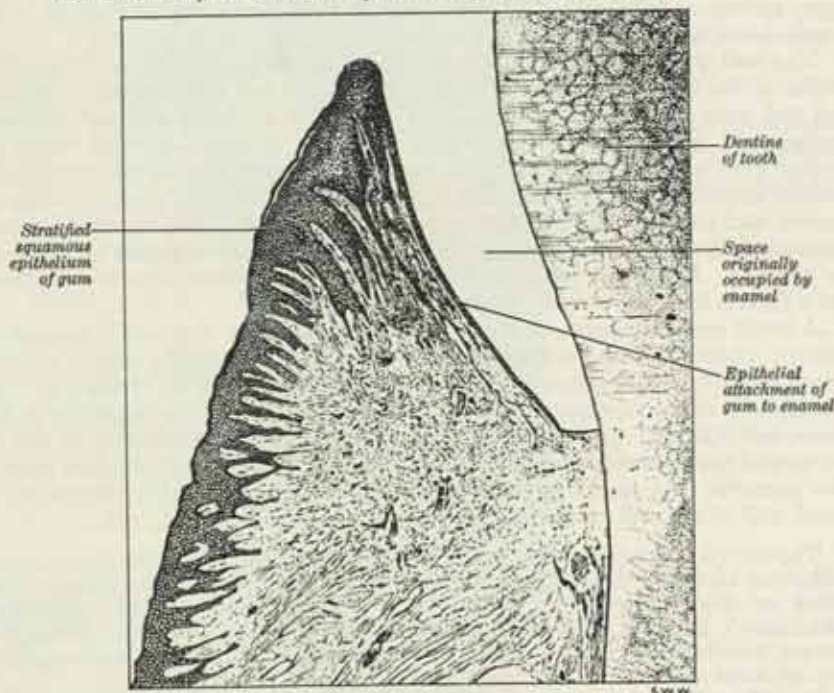
The *labial glands* are situated between the mucous membrane and the Orbicularis oris, round the orifice of the mouth. They are about the size of small peas and in structure they resemble the mucous salivary glands (see p. 1356). Their ducts open into the vestibule.

The *cheeks* form a large part of the sides of the face, and are continuous in front with the lips, the junction being indicated externally on each side by a groove, termed the *nasolabial groove*, which runs downwards and laterally from the side of

the nose to the angle of the mouth. The cheeks are composed of a muscular stratum, and a large quantity of fat, together with areolar tissue, vessels, nerves and buccal glands, covered with skin, externally, and with mucous membrane, internally.

The *mucous membrane* lining the cheek is reflected above and below on to the outer surfaces of the maxilla and mandible, whence it is continued on to the gums; it is continuous behind with the mucous membrane of the soft palate. Opposite the crown of the second upper molar tooth there is a small papilla, on the summit of which the parotid duct opens. The principal muscle of the cheek is the Buccinator; but others enter into its formation, viz. the Zygomaticus major, Risorius and Platysma.

FIG. 1113.—A section across a tooth and the adjoining part of the gum. The enamel has been decalcified and removed, leaving a space between the dentine and the thin layer of stratified epithelium of the covering gum.



The *buccal glands* are small mucous glands placed between the mucous membrane and the Buccinator muscle. Four or five, larger than the rest, and placed outside the Buccinator muscles around the terminal part of the parotid duct, are called *molar glands*; their ducts open in the mouth opposite the last molar tooth by piercing the Buccinator.

The *lymph vessels* of the cheeks and lips are described on p. 888.

The *gums* (gingivæ) (fig. 1113) are composed of dense, fibrous tissue which is immovably connected to the periosteum on the edges of the alveolar processes of the mandible and maxillæ, and covered with vascular mucous membrane. At the necks of the teeth the fibrous tissue of the gums is continuous with the periosteum lining the alveoli. In young people the stratified squamous epithelium of the gums is attached to the surface of the enamel of the teeth, but as age advances the gums recede from the enamel and in old age they are attached to the cement. Near the teeth, the mucous membrane of the gums is thrown into tall papillæ, but it becomes smooth where the gums are attached to the enamel. A few mucous glands and some 'glands of Serres' (p. 1368) are usually present. The nerves supplying the upper gum are derived from the maxillary nerve through its anterior palatine and anterior, middle and posterior superior alveolar branches. The mandibular nerve innervates the lower gum by its inferior alveolar, lingual and buccal branches, the last two supplying the corresponding surfaces of the gum. The vessels for the main part accompany the nerves. The lymphatics of the upper gum pass to the submandi-

bular modes; those from the medial part of the lower gum pass to the submental nodes, while those from its lateral part enter the submandibular nodes.

The **palate** forms the roof of the mouth: it consists of two portions—the hard palate in front, the soft palate behind.

The **hard palate** (fig. 1127) is formed by the palatine processes of the maxillæ and the horizontal plates of the palatine bones; it is bounded in front and at the sides by the alveolar arches and gums; behind, it is continuous with the soft palate. It is covered with a dense tissue, formed by the periosteum and mucous membrane, which are intimately connected. It presents a median, linear raphe, which ends anteriorly in a small papilla underlying the incisive fossa. On each side of the raphe the mucous membrane of the front part is thick, pale in colour, and corrugated; behind, it is thin, smooth, and of a redder colour: it is covered with stratified squamous epithelium, and furnished in its posterior half with numerous palatine mucous glands, which lie between the mucous membrane and the periosteum. The upper surface of the hard palate forms part of the floor of the nasal cavity and is largely lined by ciliated epithelium.

The **soft palate** (fig. 1112) is a movable fold, suspended from the posterior border of the hard palate, and extending backwards and downwards between the oral and nasal parts of the pharynx. It consists of a fold of mucous membrane enclosing an aponeurosis, muscular fibres, vessels, nerves, lymphoid tissue and mucous glands. When occupying its usual position (i.e. relaxed and pendent) its anterior surface is concave, and marked by a median raphe. Its posterior surface is convex, and continuous with the floor of the nasal cavity. Its superior border is attached to the posterior margin of the hard palate, and its sides are blended with the pharynx. Its inferior border is free. The lower portion of the soft palate hangs like a curtain between the mouth and the pharynx.

A small conical process, termed the *uvula*, hangs from the middle of its lower border; and two curved folds of mucous membrane, containing muscular fibres, extend laterally and downwards from each side of the base of the uvula (fig. 1145). The anterior of the two contains the Palatoglossus muscle and is named the *palatoglossal arch*. Below, it reaches the side of the tongue at the junction of the oral and pharyngeal portions and it forms the lateral boundary of the oropharyngeal isthmus. The posterior fold, which is termed the *palatopharyngeal arch*, descends on the lateral wall of the oral part of the pharynx and is described on p. 1382.

The *mucous membrane of the soft palate* is thin, and covered with stratified squamous epithelium excepting the anterior part of its superior surface and near the pharyngeal orifice of the auditory tube, where it is columnar and ciliated ('respiratory epithelium'), like that of the nasal cavities with which it is continuous. Beneath the mucous membrane on both surfaces there are numerous palatine mucous glands; they are most abundant on the oral surface and round the uvula.

Vessels and Nerves.—The *arteries* supplying the palate are the greater palatine branch of the maxillary artery, the ascending palatine branch of the facial artery, and the palatine branch of the ascending pharyngeal artery. The *veins* end chiefly in the pterygoid and tonsillar plexuses. The *lymph vessels* pass to the deep cervical lymph nodes. The *sensory nerves* are derived from the anterior palatine and the middle and posterior palatine (the latter two nerves containing taste fibres from the under surface of the soft palate), the nasopalatine and glossopharyngeal nerves.

The palatine aponeurosis.—A thin, firm, fibrous lamella, termed the *palatine aponeurosis*, which supports the muscles and gives strength to the soft palate, is attached to the posterior border of the hard palate and to the under surface of the hard palate behind the palatine crest. It is thick in the anterior two-thirds of the soft palate, but very thin and difficult to define farther back. The aponeurosis is actually the expanded tendon of the Tensor veli palatini and, near the middle line, it splits to enclose the Musculus uvulæ. To it, all the other muscles of the soft palate are attached. The anterior part of the soft palate contains very few muscle fibres and consists mainly of palatine aponeurosis, below which are a large number of mucous glands; it is less movable and more horizontal than the posterior part and it is upon this part that the Tensor veli palatini principally acts.

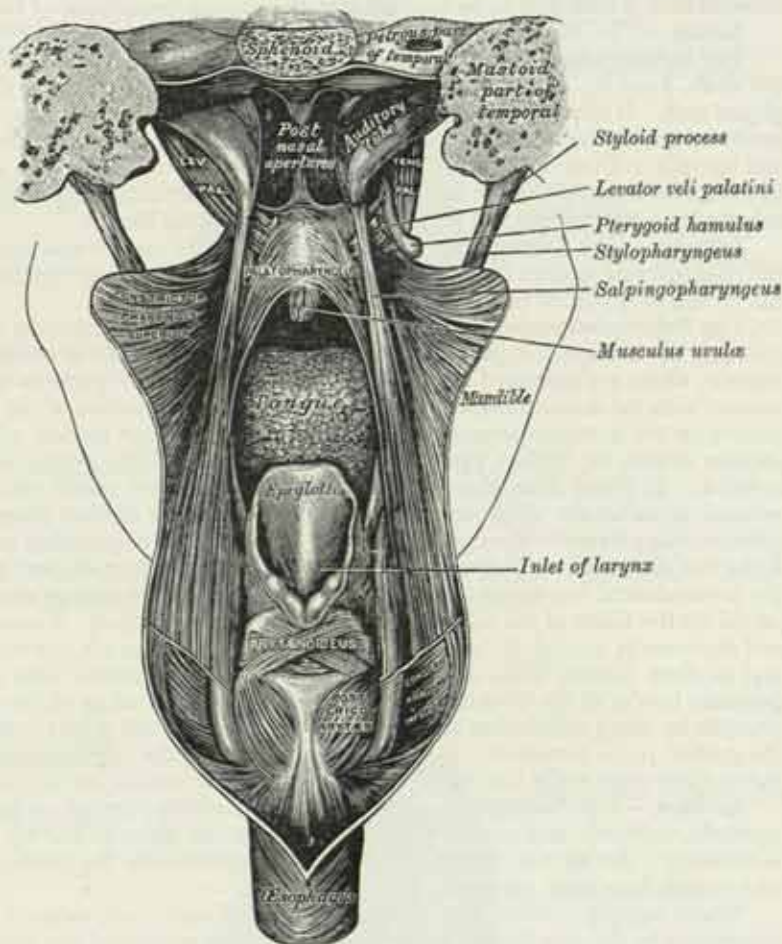
The **muscles of the palate** (fig. 1114) are:

Levator veli palatini.
Tensor veli palatini.
Musculus uvulæ.

Palatoglossus.
Palatopharyngeus.

The **Levator veli palatini** (figs. 1114, 1154, 1155) is a rounded muscle situated on the lateral side of the posterior nasal aperture. It arises * (a) by a small tendon from a rough area on the under surface of the petrous part of the temporal bone, immediately in front of the lower opening of the carotid canal; (b) by fleshy fibres from a sheet of fascia which descends from the vaginal process of the tympanic part of the temporal bone to form the upper part of the carotid sheath; and (c) by a few fleshy fibres from the inferior surface of the cartilaginous part of the auditory tube. At its origin, the muscle lies below (not medial to) the auditory tube and

FIG. 1114.—The muscles of the palate. Exposed from behind.



only crosses to the medial side of the tube at the level of the medial pterygoid lamina. After passing within the upper concave margin of the Superior constrictor and in front of the Salpingopharyngeus, it spreads out in the soft palate between the two strands of the Musculus palatopharyngeus, its fibres being inserted into the upper surface of the palatine aponeurosis as far as the median plane, where they blend with those of the opposite muscle.

Action.—The Levator veli palatini elevates the soft palate.

The **Tensor veli palatini** (figs. 1114, 1149, 1155) is a thin, triangular muscle, which lies lateral to the medial pterygoid plate, the auditory tube and the Levator veli palatini. Its lateral surface is in contact with the upper and anterior part of the Medial pterygoid muscle, the mandibular and chorda tympani nerves, the otic ganglion and the middle meningeal artery. It arises from the scaphoid fossa of the pterygoid process, the lateral lamina of the cartilage of the auditory tube and the medial aspect of the spine of the sphenoid bone. As it descends, its fibres converge

* R. F. Rohan and L. Turner, *J. Anat., Lond.*, 1956, 90, 153.

to form a delicate tendon which turns medially round the pterygoid hamulus, passes through the origin of the Buccinator muscle, and is inserted into the palatine aponeurosis and into the surface behind the palatine crest on the horizontal plate of the palatine bone. Between the tendon and the pterygoid hamulus there is a small bursa.

Actions.—Acting singly the Tensor veli palatini pulls the soft palate to one side; acting together the two muscles tighten the soft palate (principally its anterior part) and depress it by flattening out its arch.

The **Musculus uvulae** arises from the posterior nasal spine of the palatine bones and from the palatine aponeurosis, between the two laminae of which the two uvular muscles lie; it descends to be inserted into the mucous membrane of the uvula.

Action.—The Musculus uvulae pulls up the uvula on its own side.

The **Palatoglossus** is a small, fleshy fasciculus, narrower in the middle than at the ends, forming, with the mucous membrane covering its surface, the palatoglossal arch. It arises from the under surface of the palatine aponeurosis, where it is continuous with the muscle of the opposite side, and passing downwards, forwards and laterally in front of the tonsil, is inserted into the side of the tongue, some of its fibres spreading over the dorsum of the tongue, and others passing deeply into its substance to intermingle and blend with the Transversus linguae.

Actions.—The Palatoglossus pulls up the root of the tongue and approximates the palatoglossal arch to the median plane. Both muscles acting together close off the mouth cavity from the oral part of the pharynx.

The **Palatopharyngeus** (figs. 1114, 1155) forms, with the mucous membrane covering its surface, the palatopharyngeal arch. In the palate it consists of two strands, which are separated by the Levator veli palatini. The posterior strand is in contact with the mucous membrane covering the posterior surface of the palate; it joins with the posterior strand of the opposite muscle in the median plane. The anterior strand, the thicker, passes between the Levator and the Tensor veli palatini muscles. It arises from the posterior border of the hard palate and from the palatine aponeurosis, while some of its fibres join in the median plane with the corresponding strand of the opposite muscle. Both strands are attached to the upper surface of the palatine aponeurosis and lie in the same plane in the soft palate. At the posterolateral border of the palate the two layers of the muscle unite and are joined by the fibres of the Salpingopharyngeus muscle (p. 1390). Passing laterally and downwards behind the tonsil, the Palatopharyngeus descends posteromedial to, and in close contact with, the Stylopharyngeus, and is inserted with it into the posterior border of the thyroid cartilage, some of its fibres ending on the side of the pharynx by being attached to the pharyngeal fibrous coat, and others passing across the median plane posteriorly, to decussate with those of the opposite muscle. The Palatopharyngeus really forms an internal longitudinal muscular coat for the pharynx.

Actions.—The Palatopharyngeus pulls the walls of the pharynx, on its own side, upwards, forwards and medially, and so shortens the pharynx during the act of swallowing. Acting together the two muscles approximate the palatopharyngeal arches and draw them forwards.

Nerve-supply.—With the exception of the Tensor veli palatini, which is innervated by the mandibular nerve (p. 1108), all the muscles of the soft palate are supplied by the cranial part of the accessory nerve through the pharyngeal plexus.

The muscles in the soft palate lie in the following relation to each other: the palatine aponeurosis (tendon of Tensor veli palatini) forms a central sheet, enclosing the Uvular muscles near the median plane; the Levator veli palatini and Palatopharyngeus are inserted into its upper surface, the two strands of the latter muscle lying in the same plane, respectively in front of and behind the Levator veli palatini; the Palatoglossus is inserted into the under surface of the aponeurosis. (For description of the palatopharyngeal sphincter, see p. 1388.)

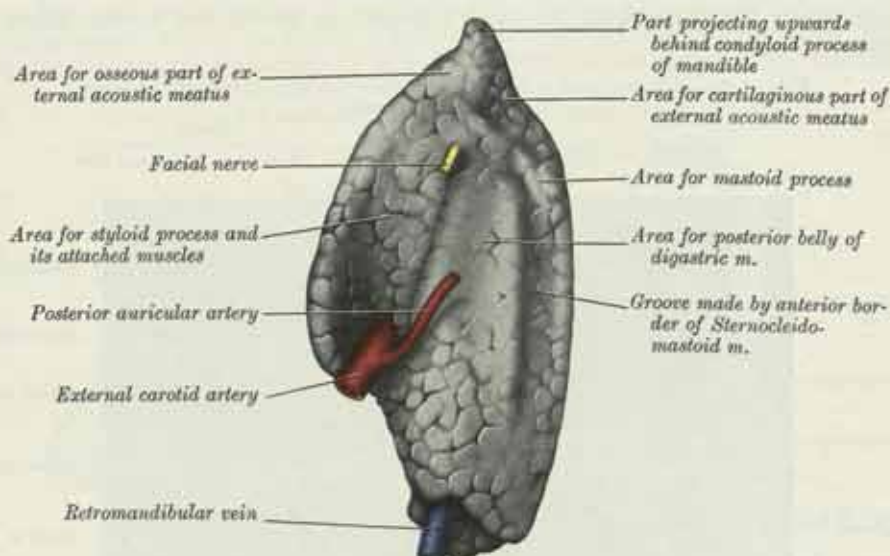
The movements of the soft palate are described on p. 1390.

Applied Anatomy.—The occurrence of a congenital cleft in the palate has been already referred to as a defect in development (p. 115). Paralysis of the soft palate may occur after diphtheria due to the action of the toxin on the nerve centres in the medulla. It gives rise to a change in the voice, which becomes nasal, and to the regurgitation of fluids into the nose when swallowing is attempted. On inspection, the palate is seen to hang flaccid and motionless when phonation or deglutition is attempted; it is also anæsthetic.

THE SALIVARY GLANDS (fig. 1118)

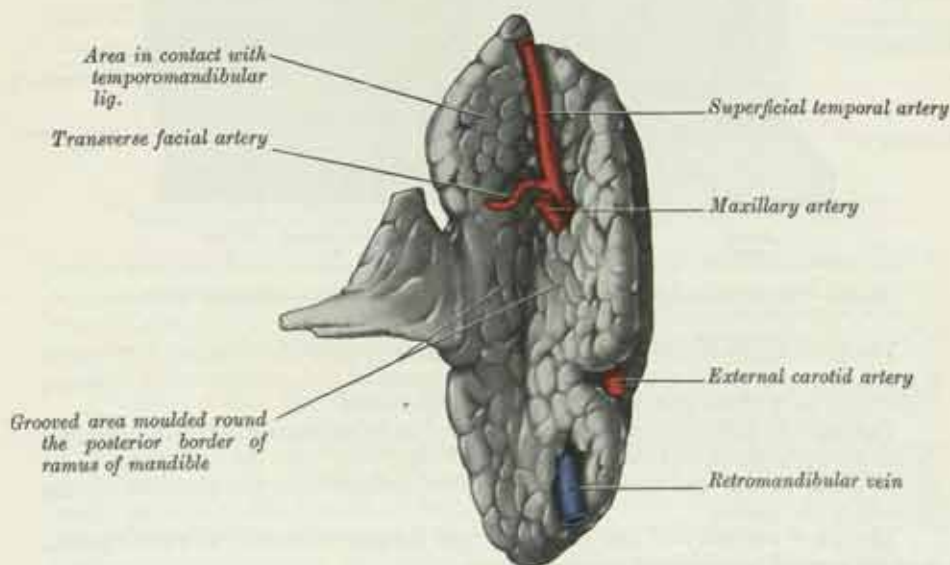
The salivary glands comprise three large paired glands—the parotid, submandibular and sublingual glands—the anterior lingual glands and numerous small glands in the mucous membrane of the tongue (p. 1380), and numerous small labial,

FIG. 1115.—The right parotid gland. Posteromedial aspect.



buccal and palatal glands (pp. 1343, 1344, 1346) in relation to the mucous membrane of the lips, cheek and roof of the mouth, respectively.

FIG. 1116.—The right parotid gland. Anteromedial aspect.

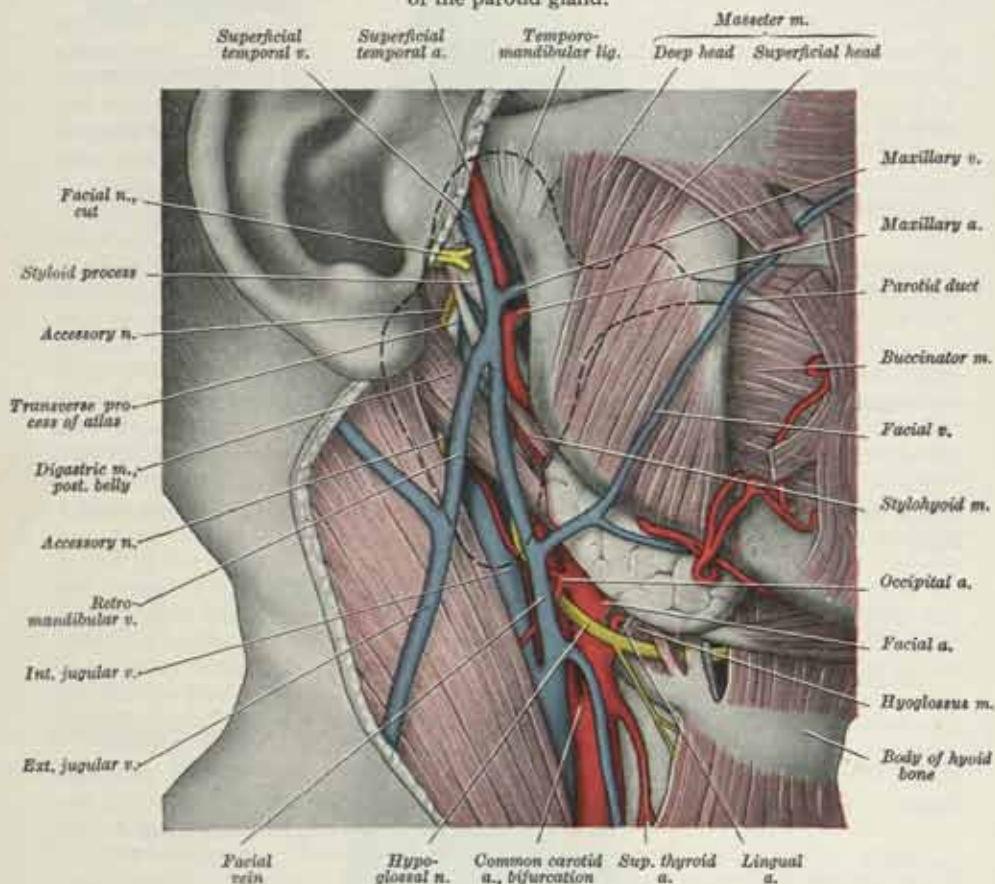


The **parotid gland** (figs. 1115, 1116) is the largest and has an average weight of about 25 gm. It forms an irregular, lobulated, yellowish mass, lying below the external acoustic meatus, between the mandible and the Sternocleidomastoid; it projects forwards on to the surface of the Masseter, where a small part of it, usually

more or less detached, lies between the zygomatic arch above and the parotid duct below ; this detached portion is named the *accessory part* of the gland.

The gland is enclosed within a capsule derived from the deep cervical fascia ; the part covering the superficial surface of the gland is dense, closely adherent to the gland, and attached to the zygomatic arch ; the deep part of the capsule is attached to the styloid process, mandible and tympanic plate, and blends with the fibrous sheaths of the muscles related to the gland ; a portion of the fascia attached to the styloid process and the angle of the mandible, is thickened to form the stylo-mandibular ligament, which intervenes between the parotid and submandibular glands.

FIG. 1117.—A drawing of a dissection to show the principal deep relations of the parotid gland.



Note.—The outline of the parotid gland is indicated by the interrupted black line.

The parotid gland may be described as roughly pyramidal in shape ; it presents a small, superior surface, and superficial, anteromedial and posteromedial surfaces. The lower part of the gland tapers to a blunt extremity.

The *superior surface* is concave and is related to the external acoustic meatus, and to the posterior surface of the temporomandibular joint ; here the auriculotemporal nerve winds round the neck of the mandible, imbedded in the gland or in the capsule of the gland.

The *lower extremity* of the gland overlaps the posterior belly of the Digastric and the carotid triangle to a variable extent.

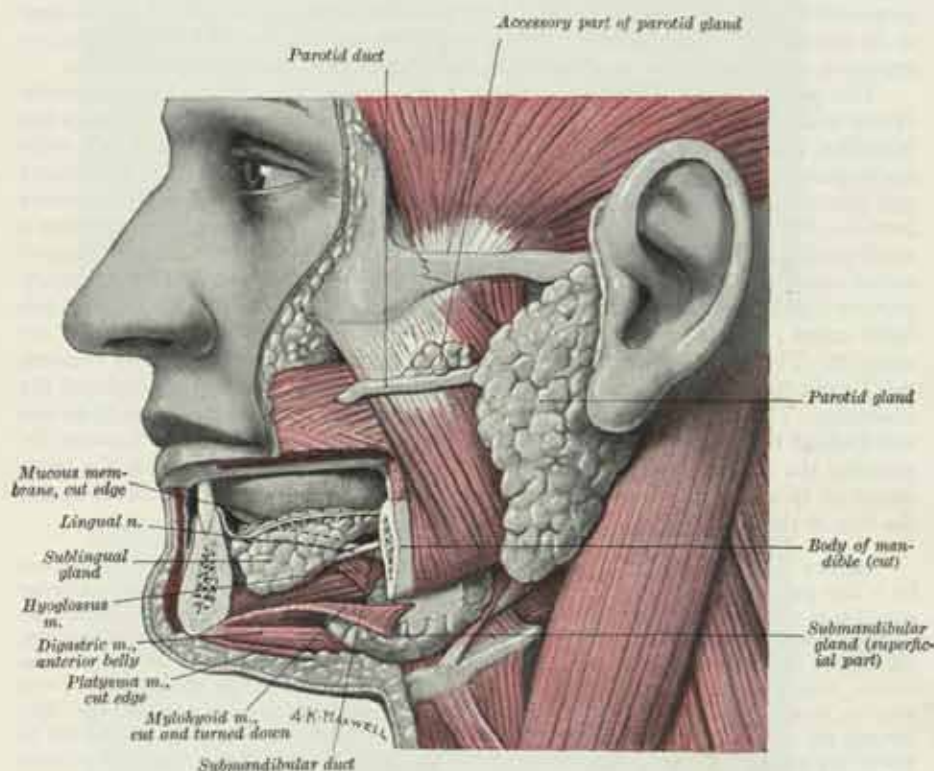
The *superficial surface* is covered with the skin, and the superficial fascia, which contains the facial branches of the great auricular nerve, the superficial parotid lymph nodes (p. 886) and the posterior border of the Platysma. It extends upwards to the zygomatic arch, backwards to overlap slightly the anterior border of the Sternocleidomastoid, downwards to its apex behind and below the angle of the mandible

and forwards across the superficial surface of the Masseter below the parotid duct (fig. 1117).

The *anteromedial surface* is grooved by the posterior border of the ramus of the mandible. It covers the postero-inferior part of the Masseter, the lateral aspect of the temporomandibular joint and the adjoining part of the mandibular ramus, and passes forwards on the deep aspect of the ramus to reach the Medial pterygoid muscle. The branches of the facial nerve emerge on the face from under cover of the anterior margin of this surface.

The *posteromedial surface* is moulded on the mastoid process and the Sternocleidomastoid, and on the posterior belly of the Digastric, the styloid process and the styloid group of muscles. The external carotid artery grooves this surface

FIG. 1118.—A dissection showing the salivary glands of the left side.



The upper portion of the superficial part of the submandibular gland has been excised and the cut Mylohyoid muscle has been turned down to expose a portion of the deep part of the gland.

before it enters the substance of the gland. The internal carotid artery and internal jugular veins are separated from the gland by the styloid process and the styloid muscles (fig. 1117). The anteromedial and posteromedial surfaces meet along a medial margin which may project so deeply as to be in contact with the side wall of the pharynx.

Structures within the gland.—The external carotid artery pierces the posteromedial surface of the parotid gland, and divides into its terminal branches within its substance. One of these branches—the maxillary artery—leaves the anteromedial surface of the gland, and runs forwards deep to the neck of the mandible, while the other—the superficial temporal artery—gives off its transverse facial branch, and then ascends to appear at the upper limit of the gland (fig. 1116). The posterior auricular artery may arise from the external carotid artery within the gland, and it then leaves the latter on its posteromedial surface. The retro-mandibular vein (p. 839), formed in the upper part of the gland by the union of the maxillary and superficial temporal veins, which enter the gland at the point of exit of the corresponding arteries, lies superficial to the intraglandular part of the external carotid artery. It emerges from the gland behind its inferior extremity

and joins the posterior auricular vein to form the external jugular vein; before it leaves the gland it gives off a communicating branch which leaves the gland in front of its lower extremity and joins the facial vein. On a still more superficial plane the facial nerve traverses the gland. It enters the upper part of the posteromedial surface (fig. 1115), and passes forwards and downwards behind the posterior border of the ramus of the mandible in two main divisions from which its terminal branches arise. These leave the anteromedial surface of the gland above, in front, and below, and pass to their destinations from under cover of its anterior margin.

Developmentally the gland arises as an outgrowth from the buccal cavity (p. 182) and extends backwards towards the ear. As it does so it covers the facial nerve, but from its deep surface prolongations of the gland penetrate between the branches of the nerve in an irregular manner and constitute its deep portion. The largest of these is found between its main temporal and cervical divisions.* These outgrowths wrap themselves round the nerve and its branches which become buried in its substance. On account of this arrangement the gland may be considered to comprise superficial and deep portions, sometimes inaccurately termed lobes.

The **parotid duct** (fig. 1118) is about 5 cm. long. It begins by the confluence of two main branches within the anterior part of the gland (*see* p. 1357), crosses the Masseter, and at the anterior border of this muscle turns inwards nearly at a right angle, passes through the corpus adiposum of the cheek (suctorial pad in the infant) and pierces the Buccinator; it then runs for a short distance obliquely forwards between the Buccinator and mucous membrane of the mouth, and opens upon a small papilla on the oral surface of the cheek opposite the crown of the second upper molar tooth. While crossing the Masseter it receives the duct of the accessory portion; in this position it lies between the upper and lower buccal branches of the facial nerve; the accessory part of the gland and the transverse facial artery are above it. The buccal branch of the mandibular nerve, as it emerges from beneath the Temporalis and Masseter, lies just below the duct at the anterior border of the Masseter. The duct can be felt in the living (on the face, or more easily in the vestibule of the mouth) as it dips inwards at the anterior border of the Masseter, by pressing the index finger *backwards* on this border of the muscle (with the teeth clenched to make the muscle tense) and moving the finger up and down across the line of the duct.

Surface Anatomy.—The anterior border of the parotid gland can be represented by a line passing downwards and forwards from the upper border of the mandibular condyle to a point just above the middle of the Masseter muscle and then downwards and backwards to a point about 2 cm. below and behind the angle of the mandible. Its upper border, concave upwards and backwards, corresponds to a curved line drawn from the upper border of the mandibular condyle, across the lobule of the auricle, to the mastoid process. The posterior border corresponds to a straight line joining the ends of the anterior and upper borders. The parotid duct corresponds to about the middle third of a line drawn from the lower border of the tragus to a point midway between the ala of the nose and the red margin of the upper lip.

Structure.—The wall of the parotid duct is of considerable thickness, and consists of a thick external fibrous coat which contains unstriped muscular fibres, and an internal mucous coat which is lined with short columnar epithelium. Its canal is about 3 mm. in diameter, but at its orifice on the oral surface of the cheek its lumen is greatly reduced in size.

Vessels and Nerves.—The *arteries* supplying the parotid gland are derived from the external carotid artery, and from the branches given off by that vessel in or near the gland. The *veins* empty themselves into the external jugular vein, through some of its tributaries. The *lymph vessels* end in the superficial and deep cervical lymph nodes, passing in their course through two or three lymph nodes on the surface and in the substance of the parotid gland. The *nerves* are derived from the auriculotemporal nerve and from the plexus of the sympathetic on the external carotid artery. It is probable that the branch from the auriculotemporal nerve is the secretomotor nerve of the gland and that it is derived from the tympanic branch of the glossopharyngeal nerve through the otic ganglion; at all events, this has been proved experimentally to be the case in some of the lower mammals.

The **submandibular gland** (fig. 1118) is irregular in form and about the size of

* J. McKenzie, *J. Anat., Lond.*, 1948, 82, 183; H. Bailey, *Brit. Med. J.*, 1947, i, 404; L. J. McCormack, E. W. Cauldwell and B. J. Anson, *Surg. Gynec. Obstet.*, 1945, 80, 620.



FIG. 1.—Radiograph of the parotid duct and its tributaries, after the injection of lipiodol through the orifice of the duct. (Sialogram: Mr. P. R. Allison.) (Reproduced by permission of the author and of the Proprietors of the *British Medical Journal*.)

Full description on p. 1357.



FIG. 2.—Radiograph of the submandibular duct and its tributaries after the injection of lipiodol through the orifice of the duct. (Sialogram: Mr. P. R. Allison.) (Reproduced by permission of the author and of the Proprietors of the *British Medical Journal*.)

Full description on p. 1357.

PLATE XXIV
Floor of maxillary sinus



First permanent molar

FIG. 1.—Radiograph of the jaws of an infant, 9 months old. (Symington and Rankin's *Atlas of Skiagrams*.)

Only the lower central incisor has erupted: the roots of the first lower milk molar are just beginning to form: the crown of the first lower permanent molar faces inwards.



Second milk molar

First permanent molar

FIG. 2.—Radiograph of the teeth of a boy, aged 5 years. (Symington and Rankin's *Atlas of Skiagrams*.)

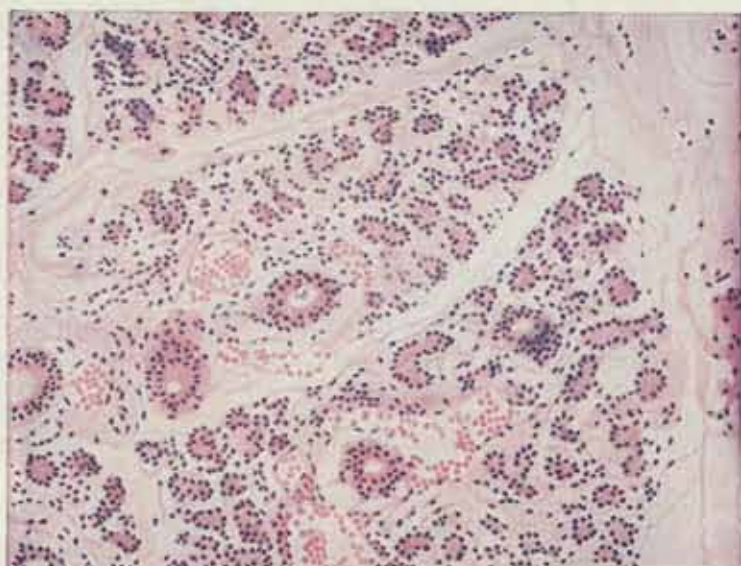
In the maxilla the lateral milk incisor and the first milk molar have been lost, but all the milk teeth are present in the mandible. No absorption of the roots of the milk teeth has yet occurred. No permanent teeth have yet erupted.

a walnut. It consists of a larger superficial part and a smaller deep part, which are continuous with each other around the posterior border of the Mylohyoid.

The *superficial part* of the submandibular gland is situated in the digastric triangle, reaching forwards to the anterior belly of the Digastric and backwards to the stylomandibular ligament, which intervenes between the submandibular and parotid glands. Above, it extends under cover of the body of the mandible; below, it usually overlaps the intermediate tendon of the Digastric and the insertion of the Stylohyoid. It has three surfaces, an inferior, a lateral and a medial, and is partially enclosed between two layers of the deep cervical fascia which extend from the greater cornu of the hyoid bone, one layer passing to the lower border of the mandible and covering the inferior surface of the gland, the other passing to the mylohyoid line on the medial surface of the mandible and covering the medial surface of the gland.

The *inferior surface* of the gland is covered by the skin, Platysma, and deep fascia.

FIG. 1119.—A section through the parotid gland, stained with hæmatoxylin and eosin. $\times 160$. Compare with fig. 1122.



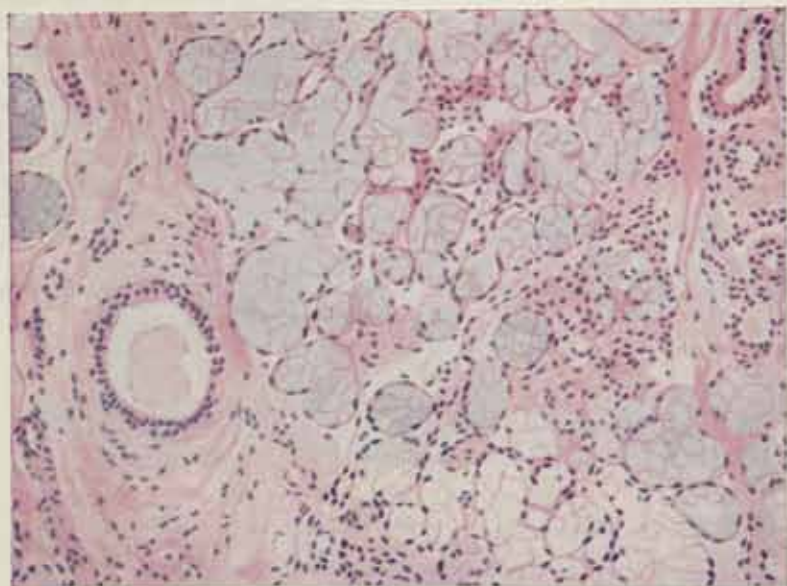
It is crossed by the facial vein, and by the cervical branch of the facial nerve; near the mandible the submandibular lymph nodes are in contact with it and a few may actually be embedded in it (p. 887).

The *lateral surface* is in relation with the submandibular fossa on the inner surface of the body of the mandible, and with the insertion of the Medial pterygoid muscle. The facial artery is embedded in a groove in the posterior and superior part of the gland, lying at first deep to the gland and then emerging between the lateral surface of the gland and the insertion of the Medial pterygoid to reach the lower border of the mandible.

The *medial surface* is related, in front, to the Mylohyoid, separated from it by the mylohyoid nerve and vessels and by branches of the submental vessels; more posteriorly, the medial surface is related to the Styloglossus, stylohyoid ligament and the glossopharyngeal nerve, which separate it from the wall of the pharynx in this region; in its intermediate part the medial surface is related to the Hyoglossus, separated from it by the Styloglossus, the lingual nerve, the submandibular ganglion, the hypoglossal nerve and the deep lingual vein (in that order from above downwards). Below, the medial surface is related to the Stylohyoid and the posterior belly of the Digastric.

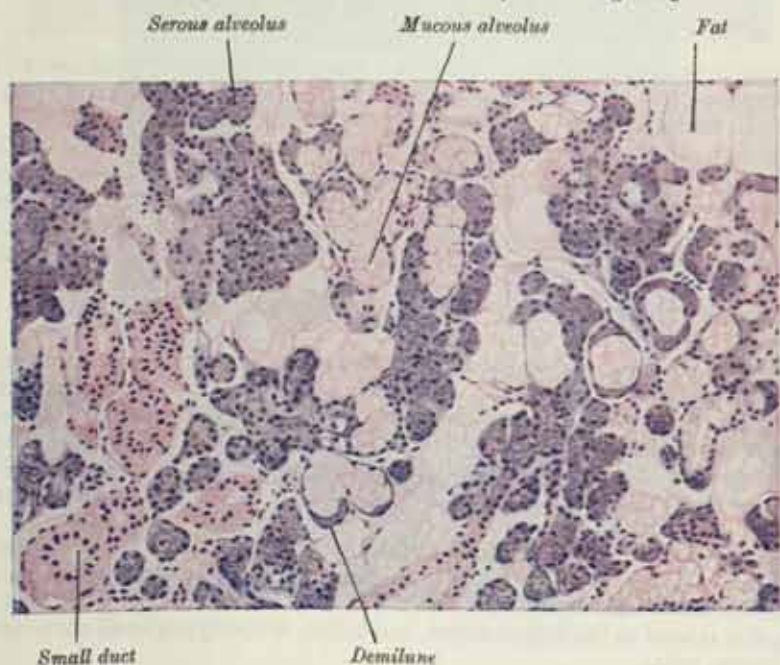
The *deep part* of the submandibular gland extends forwards as far as the posterior end of the sublingual gland, and lies in the intermuscular interval between the Mylohyoid below and laterally, and the Hyoglossus and Styloglossus medially; above, it is related to the lingual nerve, and below, to the hypoglossal nerve and the deep lingual vein.

FIG. 1120.—A section through the sublingual gland, stained with hæmatoxylin and eosin. $\times 160$. Compare with fig. 1124.



The **submandibular duct** is about 5 cm. long, and its wall is much thinner than that of the parotid duct. It begins by numerous branches in the superficial part of the gland and, emerging from the middle of the deep surface of that part of the gland, a little behind the posterior border of the Mylohyoid, it runs beneath the deep part of the gland passing at first upwards and slightly backwards for 4 or 5 mm. and then turns forwards to run between the Mylohyoid and the Hyoglossus; it then passes between the sublingual gland and the Genioglossus, and opens by a narrow orifice on the floor of the mouth, on the summit of the sublingual papilla at

FIG. 1121.—A section of the submandibular gland, stained with hæmatoxylin and eosin. $\times 160$. Compare with fig. 1123.

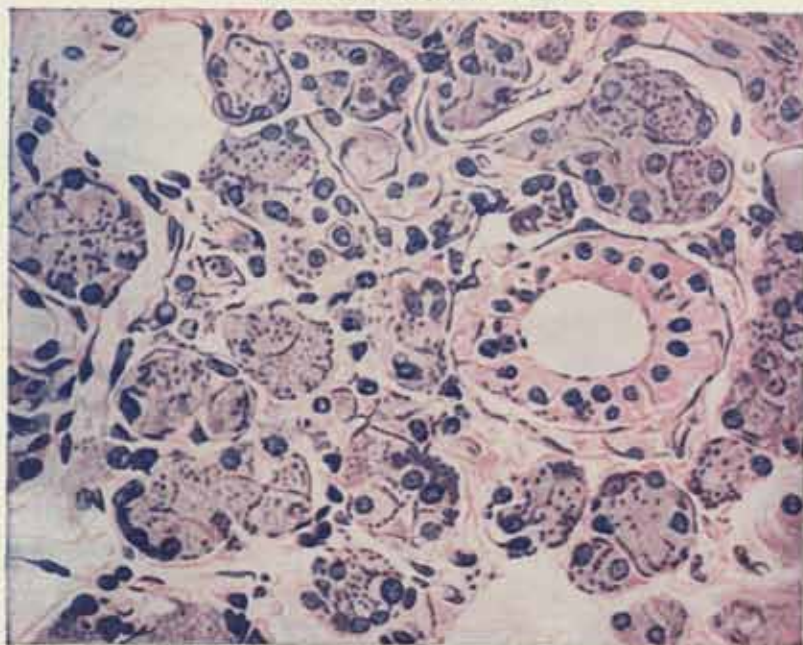


the side of the frenulum of the tongue (fig. 1144). On the Hyoglossus it lies between the lingual and hypoglossal nerves, but at the anterior border of the muscle it is crossed laterally by the lingual nerve; the terminal branches of the lingual nerve ascend on its medial side (fig. 935).

Vessels and Nerves.—The *arteries* supplying the submandibular gland are branches of the facial and lingual arteries. Its *veins* follow the course of the arteries. The *nerves* are derived from the submandibular ganglion, through which it receives filaments from the chorda tympani of the facial nerve, the lingual branch of the mandibular nerve and the sympathetic.

In the dog and cat the submandibular gland receives its nerve-supply through Langley's ganglion (p. 1357), but in the human the cell-stations on the parasympathetic nerve-supply of the gland (chorda tympani) are probably in the submandibular ganglion.

FIG. 1122.—A section through the parotid gland, stained with hæmatoxylin and eosin. $\times 400$.



The **sublingual gland** (fig. 1118) is the smallest of the three main salivary glands. It is situated beneath the mucous membrane of the floor of the mouth, in contact with the sublingual fossa on the inner surface of the mandible, close to the symphysis. It is narrow, flattened, shaped somewhat like an almond, and weighs between 3 and 4 gm. It is in relation, *above*, with the mucous membrane of the mouth, which it raises in the form of the sublingual fold; *below*, with the Mylohyoid; *in front*, with its fellow of the opposite side; *behind*, with the deep part of the submandibular gland; *laterally*, with the mandible above the anterior part of the mylohyoid line; and *medially*, with the Genioglossus, from which it is separated by the lingual nerve and the submandibular duct. Its excretory ducts are from eight to twenty in number. Of the *smaller sublingual ducts*, most open separately into the floor of the mouth on the summit of the sublingual fold; occasionally a few open into the duct of the submandibular gland. From the anterior part of the gland some of the ducts sometimes join to form a *major sublingual duct*, which opens with, or near to, the submandibular duct.

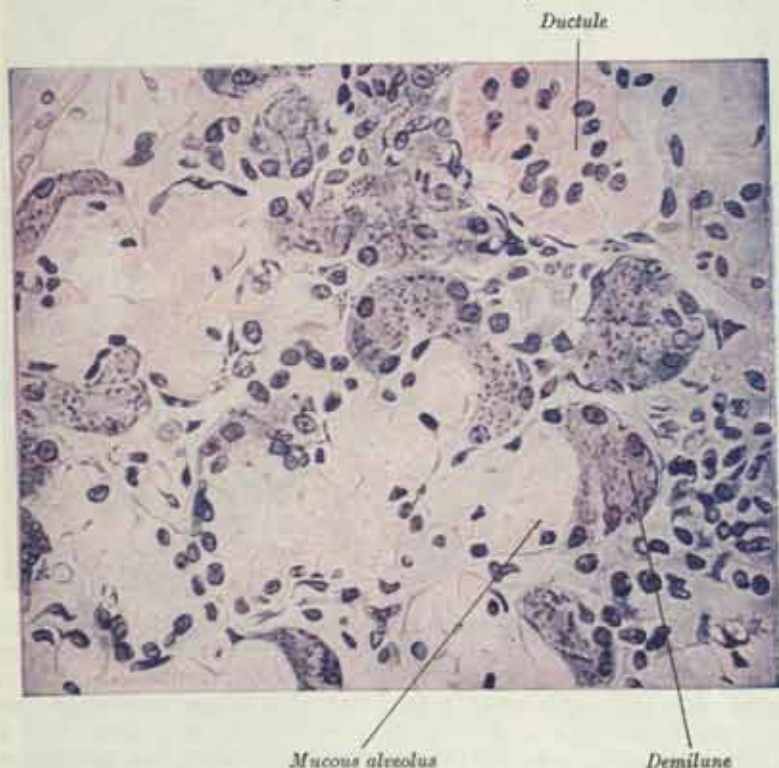
Vessels and Nerves.—The sublingual gland is supplied with blood by the sublingual and submental arteries. Its nerves are derived from the lingual and chorda tympani nerves, and from the sympathetic. The parasympathetic cell-station is in the submandibular ganglion; occasionally some nerve-cells are found on the fibres passing distally from the submandibular ganglion to the lingual nerve and they constitute a sublingual ganglion.

Structure of the salivary glands.—The salivary glands are compound racemose glands, consisting of numerous lobes, which are made up of lobules, connected together by dense areolar tissue, vessels and ducts. Each lobule consists of the ramification of a single duct, the branches ending in slightly dilated ends or alveoli on which the capillaries are distributed. The alveoli are enclosed by a basement-membrane, which is continuous with the membrana propria of the duct and consists of a network of branched and flattened nucleated cells.

The alveoli of the salivary glands are of two kinds, viz. serous and mucous, which differ in the nature of their secretion and in the appearance of their cells. (1) The mucous alveoli secrete a viscid fluid which contains mucin; (2) the serous secrete a thinner and more watery fluid. The parotid gland contains only serous alveoli. The submandibular and sublingual glands contain both serous and mucous alveoli; most of those in the submandibular gland are serous, whereas the majority in the sublingual gland are mucous.

The cells in the *mucous alveoli* are columnar in shape (fig. 1124), and in the fresh condition contain large granules of mucinogen. In hardened preparations a delicate protoplasmic network is seen, and the cells are clear and transparent. The nucleus is

FIG. 1123.—A section through the submandibular gland, stained with hematoxylin and eosin. $\times 400$.



usually situated near the basement-membrane and is flattened. In some mucous alveoli peculiar crescentic bodies are seen between the cells and the basement-membrane. They are termed the *crescents of Giannuzzi*, or the *demilunes of Heidenhain* (fig. 1121), and are composed of polyhedral granular cells. Fine canaliculi pass between the mucus-secreting cells from the demilunes to reach the lumen of the alveolus.

In the resting condition of the gland the cells in the *serous alveoli* fill the cavity almost completely, so that the lumen is barely perceptible; they contain granules imbedded in a closely reticulated protoplasm (fig. 1122). The cells are more cubical and the granules smaller than those of mucous alveoli; the nucleus of each is spherical and placed near the centre of the cell. The granules are the antecedents of the enzyme, *ptyalin*.

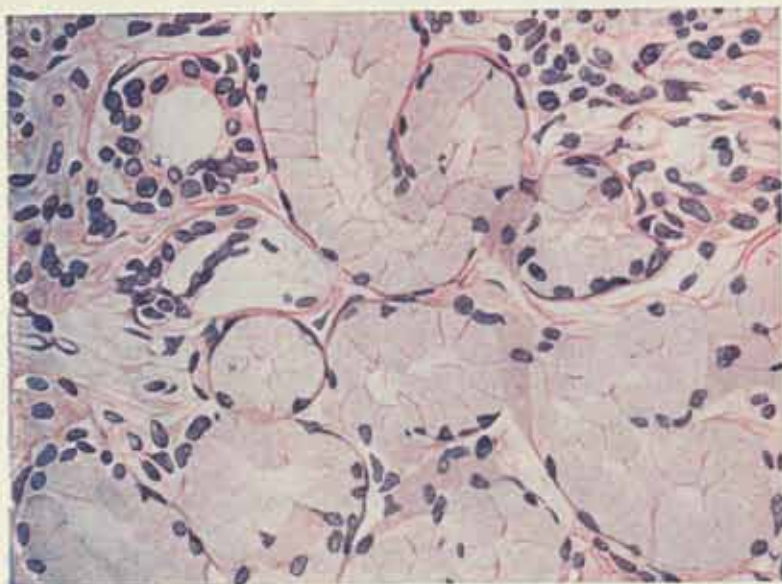
Both mucous and serous cells vary in appearance according to whether the gland is in a resting condition or has been recently active. In the former case the cells are large and contain many granules; in the latter case the cells are shrunken and contain few granules, chiefly collected at the inner ends of the cells. The granules are best seen in fresh preparations.

The ducts are lined at their origins by low cubical epithelium, but as they enlarge, the epithelial cells change to the columnar type and the part of the cell next the basement-membrane is finely striated; near the opening into the mouth the epithelium becomes stratified.

The lobules of the salivary glands are richly supplied with blood-vessels, which form a dense network in the inter-alveolar spaces. Fine plexuses of nerves are also found in the interlobular tissue. The nerve-fibrils pierce the basement-membrane of the alveoli, and end in branched varicose filaments between the secreting cells. In the hilus of the submandibular gland in some animals there is a collection of nerve-cells termed *Langley's ganglion*.

Accessory glands.—Besides the salivary glands proper, numerous other glands are found in the mouth. Some of these occur in the tongue (p. 1380); others lie around and in the tonsil between its crypts, and large numbers are present in the soft palate, the posterior part of the hard palate, the lips and cheeks. These glands are of the same structure as the larger salivary glands and are mainly of the mucous type.

FIG. 1124.—A section through the sublingual gland, stained with hematoxylin and eosin. $\times 400$.



Sialography.—A cannula can be introduced into the openings of the parotid and submandibular ducts and lipiodol (a substance opaque to X-rays) can be injected into the duct systems of these glands. The normal pattern and calibre of these systems, or their obliteration or dilatation by disease, can then be revealed by radiography. The *parotid duct*, as seen in sialograms (lateral view), is formed about the middle of the posterior border of the ramus of the mandible by the union of two ducts, of slightly smaller calibre, which pass upwards and downwards, respectively, to join the main parotid duct at right angles to its course (Pl. XXIII, fig. 1). As it runs across the face, the parotid duct receives from above five or six very small ductules from the accessory parotid gland, and as it bends inwards at the anterior border of the Masseter, it is often compressed by that muscle so that the shadow of the lipiodol is here considerably attenuated. The intraglandular part of the main duct receives an alternating series of descending and ascending tributaries. Each of the main tributaries of the duct is formed in turn from an arborization of fine ductules, which are the terminal ducts and alveoli. The latter normally show no dilatation but are represented in sialograms by the tiny endings of the smallest ducts. The *duct of the submandibular gland* commences from the lowest part of the gland (below the lower border of the body of the mandible as seen in lateral views), passes vertically upwards to just above the lower border of the body of the mandible, and here turns sharply forwards and gradually ascends to its opening. The vertical part of the duct receives tributaries on both its anterior and posterior aspects and as it turns sharply forwards it receives a large tributary from the posterior part of the

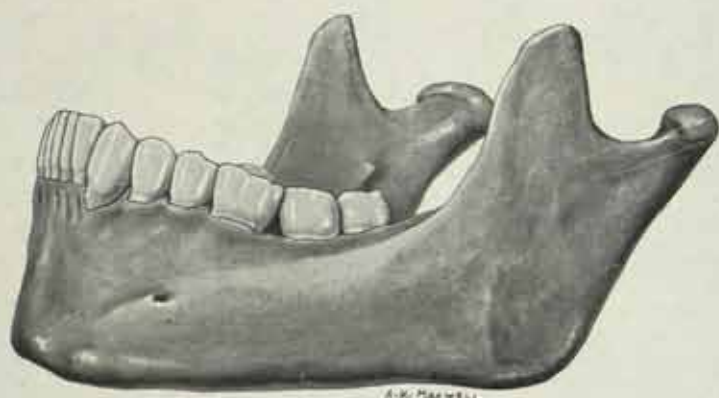
gland (Pl. XXIII, fig. 2). Each tributary is formed from an arborization of ductules (with their terminal alveoli) which have the same appearance as that described in the case of the parotid. Sometimes when lipiodol is injected into the submandibular duct, it passes also into the major sublingual duct, and the ductules of the anterior part of the sublingual gland are then revealed in the sialogram.

THE TEETH (DENTES)

Man is provided with two sets of teeth, which make their appearance at different periods of life. Those of the first set are temporary and erupt through the gums during the first and second years; they are called the *deciduous* or *milk* teeth. Those of the second set begin to erupt and replace the deciduous teeth about the sixth year; they have all erupted by the twenty-fifth year (except the third molar tooth, the **wisdom tooth** or *dens serotinus*, which may not erupt at all or, indeed, may fail to develop), and, since they may be retained until old age, they are named the *permanent* teeth.

The *deciduous* teeth are twenty in number: four incisors, two canines, and four molars in each of the upper and lower jaws. The *permanent* teeth are thirty-two in

FIG. 1125.—The lower dental arch. Labial surface. Drawn from an original photograph by Professor Francis Davies.



Note the 'curve of Spee', which passes from the apex of the canine tooth to the masticatory surface of the third molar and, continued onwards, passes through the condyle of the mandible.

number: four incisors, two canines, four premolars (or bicuspid), and six molars in each jaw. The *dental formulæ* may be represented as follows:

Deciduous Teeth.

	mol.	can.	in.	in.	can.	mol.	
Upper jaw	2	1	2	2	1	2	Total 20
Lower jaw	2	1	2	2	1	2	

Permanent Teeth.

	mol.	premol.	can.	in.	in.	can.	premol.	mol.	
Upper jaw	3	2	1	2	2	1	2	3	Total 32
Lower jaw	3	2	1	2	2	1	2	3	

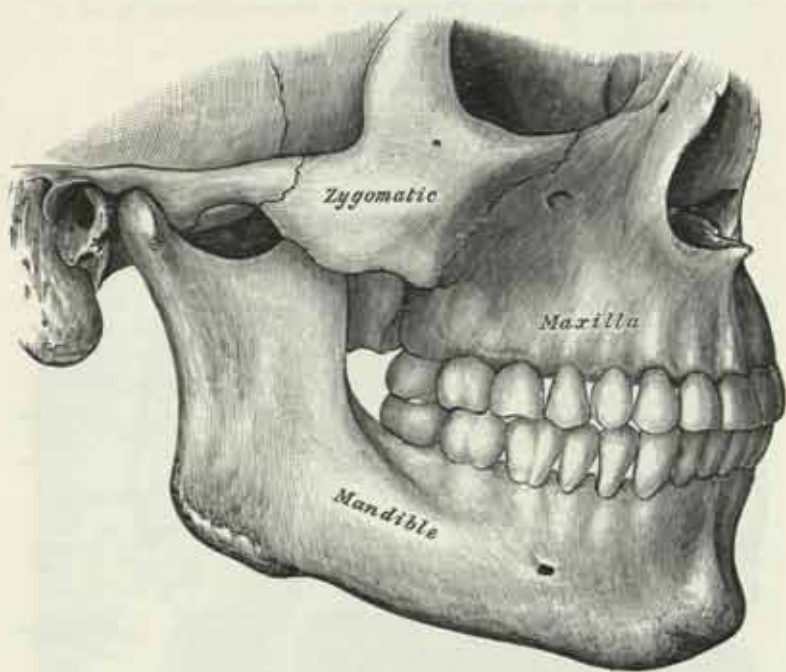
The dental formula for the permanent dentition in man is usually expressed briefly as $I_{\frac{2}{2}} C_{\frac{1}{1}} Pm_{\frac{2}{2}} M_{\frac{3}{3}}$ (for one side of each jaw).

General characteristics.—Each tooth consists of three parts: the *crown*, projecting beyond the gum; the *root*, imbedded in the alveolus of the maxilla or mandible; and the *neck*, the constricted part between the crown and the root (fig. 1132). In the centre of all these parts of the tooth is a soft substance called the *pulp*. Immediately outside the pulp is a yellowish-white layer, termed the *dentine*, which forms the main bulk of the tooth. Covering the dentine in the region of the crown is a thin,

white, hard layer, termed the *enamel*, whilst covering the dentine of the root is a layer—the *cement*—which has a structure resembling that of bone. At the apex of each root there is a small foramen in the cement and dentine, through which blood-vessels and nerves pass into the pulp. The roots are firmly implanted in the alveoli of the maxillæ and mandible, being retained in these sockets by the *periodontal membrane* (*dental periosteum*), which covers the cement of the root and lines the alveoli (fibrous joint, of the type gomphosis) (p. 451). This periosteum is continued as far as the neck of the tooth where it merges into the fibrous tissue of the gums. The periodontal membrane is normally about 0.2 mm. thick and extremely slight movement is allowed between the tooth and its socket.

In consequence of the curve of the dental arches of the mandible and maxillæ, the ordinary descriptive terms such as anterior and posterior, if applied to the teeth, would be confusing, and special descriptive terms are commonly employed by dental surgeons for the sake of clarity. The surface of a tooth directed towards the

FIG. 1126—The teeth and jaws. Right lateral aspect.



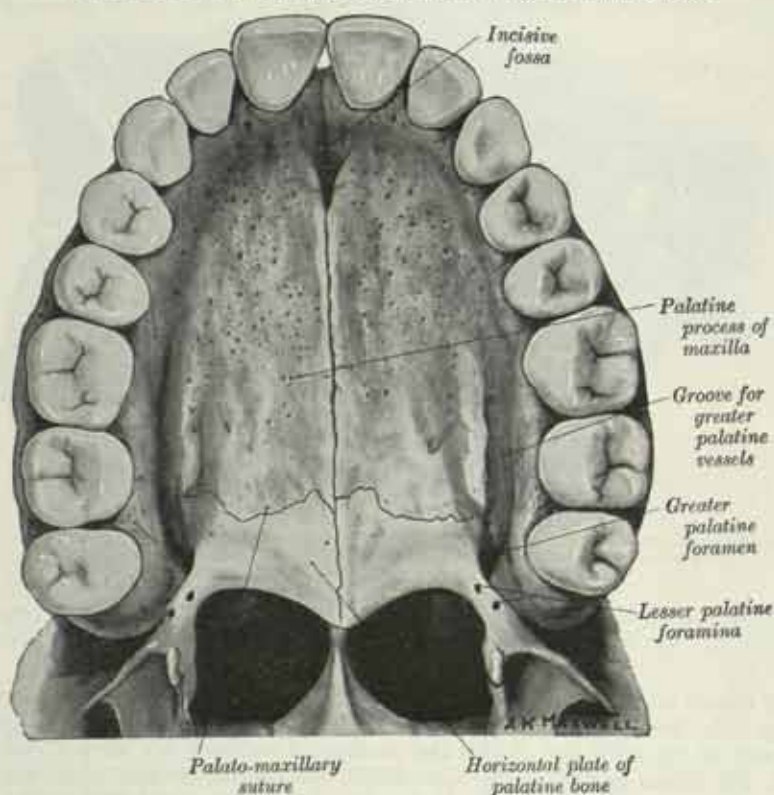
lips or cheeks is known as the *labial* (or buccal, or facial) surface; that towards the tongue is the *lingual* (or palatal) surface. Those surfaces which face the neighbouring teeth of the same jaw, that is the contiguous surfaces, are termed *mesial* and *distal*, the mesial surface being that nearer the central incisor, while the distal surface is nearer the third molar. In the case of the incisors and canines, the mesial surfaces are medial and the distal surfaces lateral, while in the premolars and molars, the mesial surfaces are anterior and the distal surfaces posterior. The surfaces of the teeth of the upper and lower jaws which meet when the mouth is closed are called the *masticatory*, *occlusal* or *chewing* surfaces. The upper central incisors are wider than the lower, with the result that the masticatory surfaces of the corresponding teeth of the upper and lower jaw are not accurately opposed to each other when the mouth is closed. Thus the upper canine occludes partly with the lower canine and partly with the first premolar, and the tubercles of the upper molars lie distal to the corresponding tubercles of the lower molars. The two dental arches, however, end at nearly the same plane behind, because the upper molars, especially the third, are smaller than the lower. The maxillary dental arch forms an elliptical curve, the sides of which are nearly parallel, slightly approaching each other distally (fig. 1127). The mandibular dental arch, on the other hand, forms a parabolic curve, and in front is narrower, and behind wider, than the maxillary arch (fig.

1128). Consequently, the upper teeth overlap the lower on their labial aspects, and the upper molars slope downwards and outwards while the lower molars slope upwards and inwards, this tilting being known as the curve of Monson. The masticatory surfaces of the lower teeth, distal to the incisors, do not all lie in the same plane but along a curve which is concave upwards (curve of Spee); this curve in the adult is an arc of a circle of approximately three and a half inches radius; the circumference of this circle also passes through the condyle of the mandible (fig. 1125). The masticatory surfaces of the upper teeth lie on a corresponding curve which is convex downwards. These curves are of importance in prosthetic dental surgery in the construction of artificial dentures.

THE PERMANENT TEETH (figs. 1126 to 1129 and Pl. XXV).

The **incisor teeth** are so named because the masticatory edge of the chisel-shaped crown of each is bevelled so as to present a sharp, cutting, horizontal edge,

FIG. 1127.—The permanent teeth of the upper dental arch. Inferior aspect.
Drawn from an original photograph by Professor Francis Davies.



an adaptation for biting the food. They are eight in number and form the four front teeth in each dental arch.

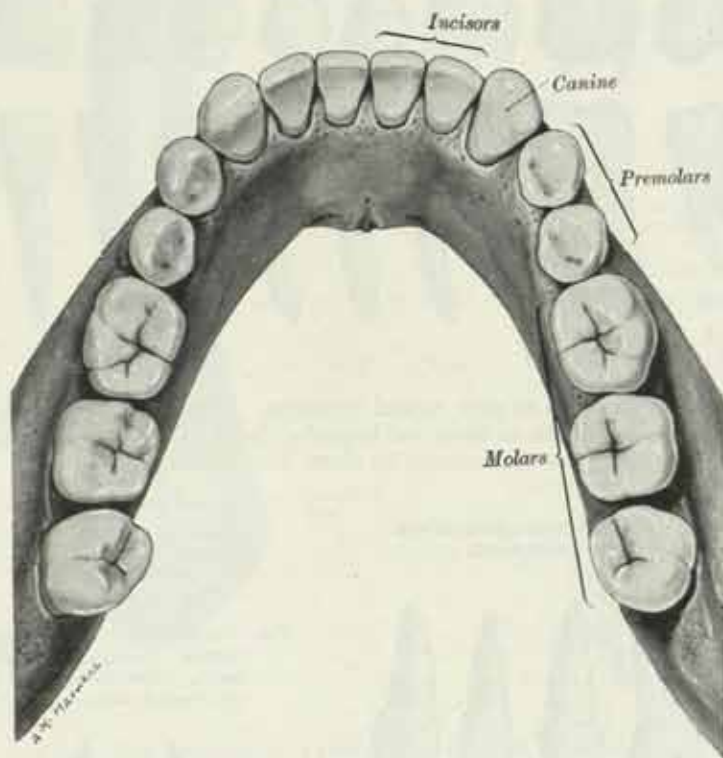
The **crown** is convex on its labial surface and concave on its lingual surface, except near the neck, where this surface becomes convex. In early life, before it is subjected to wearing down by mastication, the masticatory edge has three small prominent points, separated by two notches. The **neck** is slightly constricted. The **root** is single.

The **upper incisors** are larger than the lower and are directed obliquely downwards and forwards. They overlap the lower incisors and their cutting edges are consequently bevelled at the expense of their lingual surfaces. The lingual surface of the crown frequently presents a V-shaped eminence, known as the **cingulum**, the apex of which is near the neck, where a distinct **lingual tubercle** is sometimes developed. The root is long, conical and nearly circular in transverse section. The central upper incisors are the largest of the incisor teeth.

The *lower incisors* are placed almost vertically, and their cutting edges are bevelled at the expense of their labial surfaces as they have been worn down by contact with the overlapping edges of the upper teeth. Their roots are flattened mesio-distally and are grooved on their mesial and distal surfaces. The lower central incisor is the smallest of the incisor teeth; its root is very short.

The **canine teeth** are four in number, two in the upper and two in the lower jaw. Each is placed distal to the corresponding lateral incisor. They are longer than the incisors. Each has a large, long root, which causes a well-marked bony prominence on the facial surface of the maxilla or mandible. The crown is large and conical, very convex on its labial surface, slightly concave on its lingual surface, and its masticatory edge tapers to a blunted point, which projects slightly beyond the level of the other teeth. The root is single, longer and thicker than that of an incisor, and is conical in shape.

FIG. 1128.—The permanent teeth of the lower dental arch. Superior aspect. Drawn from an original photograph by Professor Francis Davies.



The *upper canines* (popularly called the 'eye-teeth') are larger than the lower, and usually have a distinct cingulum. The root is the largest of all in the human teeth.

The *lower canine* bites between the canine and lateral incisor of the upper jaw. Its root is slightly flattened mesio-distally and grooved on its mesial and distal surfaces; very rarely, the root is double. The crown usually has no cingulum.

The **premolar (or bicuspid) teeth** are eight in number, four in each arch. They are smaller and shorter than the canines, and are placed distal to them. The crown of each is compressed mesio-distally and is surmounted by two pyramidal tubercles or cusps, one labial and the other lingual. The root is usually single, flattened mesio-distally, and deeply grooved longitudinally on its mesial and distal surfaces, indicating a tendency for it to become double; the root of the first upper premolar is generally bifurcated.

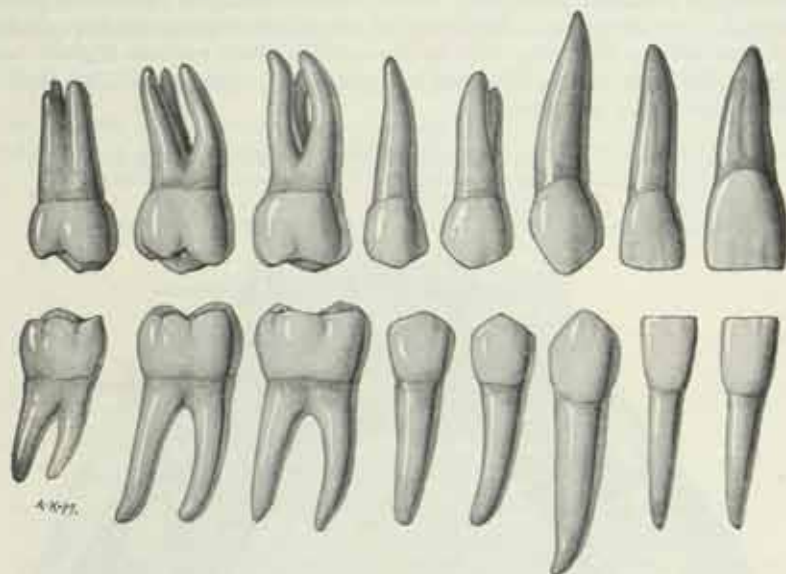
The *upper premolars* are larger than the lower. The two tubercles on the crown are separated by a groove. The labial tubercle of the first premolar is larger than the lingual, whereas the tubercles of the second premolar are practically the same size.

In the *lower premolars* the labial and lingual tubercles of the crown are connected

by a ridge, mesial and distal to which is a small pit. The lingual tubercle of the first premolar is very small, and may be merely rudimentary, whereas in the second premolar the labial and lingual tubercles are nearly equal in size. Owing to variations it is often impossible to identify with certainty individual premolar teeth.

The **molar teeth** are the largest of the permanent set and their broad crowns are adapted for grinding the food. They are twelve in number, six in each arch,

FIG. 1129.—The permanent teeth of the right side, labial surfaces.



three being placed distal to each second premolar. The crown of each is nearly cubical in form, convex on its labial and lingual surfaces, and flattened on its mesial and distal surfaces. It is surmounted by three, four, or five tubercles.

FIG. 1130.—The deciduous teeth of the right side, labial surfaces.

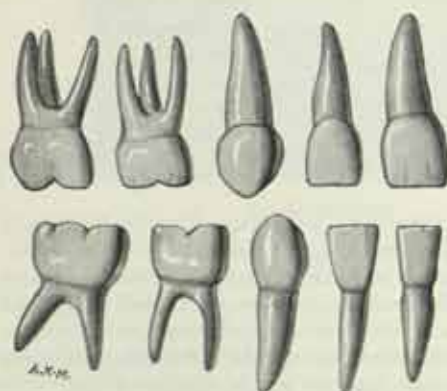


FIG. 1130A.—The left upper second deciduous molar tooth. Note the form of the two buccal roots. $\times 1.67$.



The **upper molars**.—The first molar is usually larger than the second; the third is a small tooth (fig. 1129). The crown of the first molar has four tubercles, of which the disto-lingual is the smallest; that of the second molar has either three or four cusps, and that of the third molar three cusps, the disto-lingual cusp being absent. Where four cusps are present in the upper molars, a ridge connects the mesio-lingual to the disto-labial cusp. The labial tubercles project more than the lingual. Each upper molar has three roots, two of which are labial and nearly parallel to each other, while the third (which is the largest) is lingual and diverges from the others

as it ascends; this divergence of the roots is greater in the first than in the second molar, while the roots of the third molar are more or less fused together.

The *lower molars*.—These are larger than the upper molars. On the crown of the first there are five tubercles, of which the disto-labial tubercle is the smallest. The crowns of the second and third molars have either four or five tubercles, the disto-labial tubercle being inconstant. Each lower molar has two roots, a mesial and a distal, which are curved distally as they descend, flattened mesio-distally, and grooved on their mesial and distal surfaces; the two roots of the third molar are more or less united.

FIG. 1131.—Vertical ground section of first lower molar tooth. *In situ*. $\times 62$.

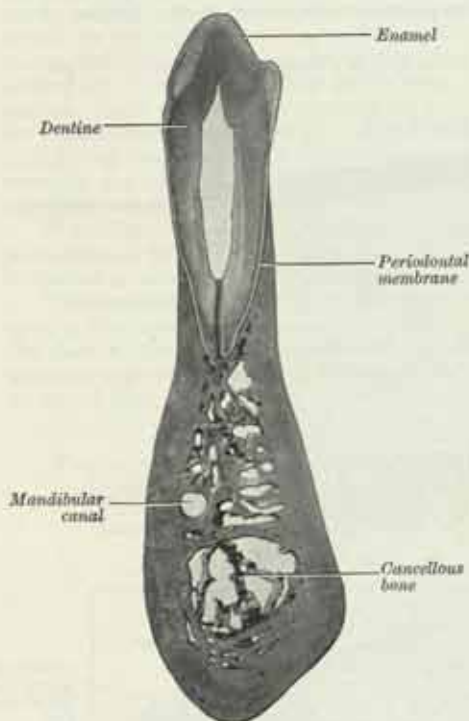
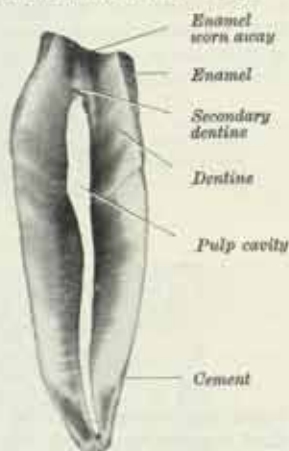


FIG. 1132.—A vertical section through a molar tooth.



FIG. 1133.—Vertical ground section of an incisor tooth. $\times 2.5$.



THE DECIDUOUS TEETH (fig. 1130 and Pl. XXIV)

The **deciduous** or **milk teeth** resemble in form the teeth which bear the same names in the permanent set; they are, however, smaller and their necks are more constricted. The second molar is the largest of the deciduous teeth. The first upper molar has three tubercles, the second has four. The first lower molar has four tubercles; the second has five. The roots of the deciduous molars are smaller than those of the permanent molars; they are also more divergent, owing to the fact that the crowns of the (permanent) premolars are lodged between them but the apices of the *fully developed* roots are convergent (fig. 1130 A). The deciduous molars are replaced by the premolars.

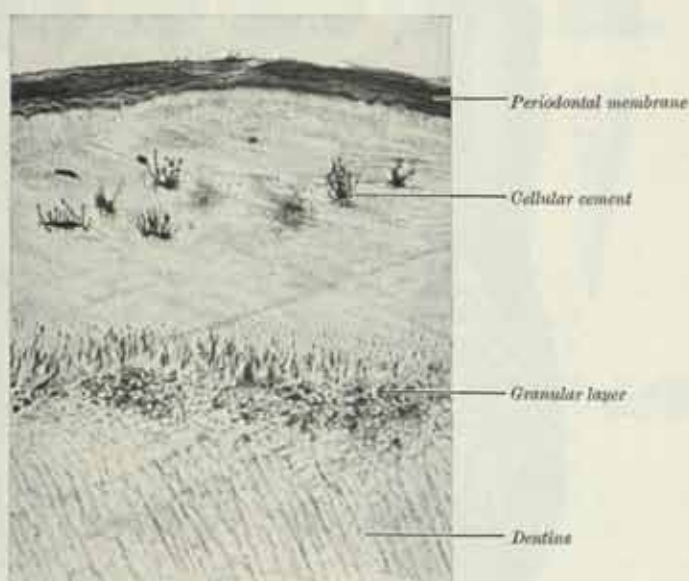
THE STRUCTURE OF THE TEETH

When a vertical section is made through a tooth (figs. 1131 to 1133), a cavity is seen in the crown, neck and centre of each root; it opens by a minute orifice at the extremity of the latter. This is called the *pulp cavity*, and contains the *dental pulp*, a loose connective tissue, containing a gelatinous substance, and richly supplied with blood-vessels and nerves which enter the pulp through the orifice at the apex of each root. Branched connective tissue-cells permeate the pulp. In the young tooth, a single

layer of large, elongated, granular cells lies on the surface of the pulp, adjacent to the deep surface of the dentine. These are called the *odontoblasts*, because they are concerned with the formation of the dentine. Each odontoblast contains a large nucleus, situated in the deeper part of the cell. The form of these cells changes with age. During the process of development of the dentine they have the shape described above, but after the dentine is fully formed they become shrunken and flattened. Each odontoblast sends a fine protoplasmic process from its superficial extremity into the small canaliculi or tubules which lie in the dentine. In general, the pulp cavity has the same shape as that of the entire tooth; it extends as small horns (*cornua*) into the tubercles of the crowns. Owing to its rich nerve-supply, the pulp is extremely sensitive and tactile and thermal stimulation produce pain.

The *dentine*, which forms the bulk of the tooth, is a hard, elastic, yellowish-white substance, consisting of a number of minute tubules (the *dental canaliculi* or *dental tubules*) imbedded in a dense matrix which consists of 28 parts of organic matter and 72 parts of inorganic salts (mainly calcium phosphate). The tubules open into the pulp cavity and pursue a wavy course (the primary curvatures) in the dentine of the

FIG. 1134.—Ground transverse section of the root of a tooth, near the apex. $\times 142$.



crown and a straight course in the root; in each case the tubules also present secondary curvatures in the form of spiral coils. Each tubule has side branches which communicate with those of adjacent tubules. In general, the tubules run vertically beneath the masticatory surface of the crown, horizontally in the sides of the crown and in the neck, and obliquely towards the apex in the root. Around the lumen of each tubule there are two layers of calcified dentine, an inner clear and an outer granular zone, separated from each other by a thin homogeneous membrane, the so-called *dental sheath*.^{*} The lumen of each tubule contains a *dental fibre* (of Tomes), which is a protoplasmic prolongation of an odontoblast cell and which may be concerned with nourishing the avascular dentine. After decalcification with acids, dentine retains its shape. In longitudinal sections of a tooth, lines can be seen in the dentine which run parallel to the walls of the pulp cavity; they are called the contour lines (of Owen) and are formed by small imperfectly calcified areas, termed the *interglobular spaces*. These spaces are most marked just below the amelo-dental junction in the crown and just below the dentino-cemental junction in the root; in the root the spaces are much smaller than in the crown and comprise the *granular layer* (of Tomes) (fig. 1134). The spaces are surrounded by fully calcified dentine. Other curved lines, concentric with the pulp, and called the *lines of Schreger*, are seen in transverse sections of dentine; they are due to the optical effect of simultaneous curvature of the dental tubules.

In young teeth, where dentine is being formed, a clear layer is seen lying between the odontoblasts and the fully-formed dentine. It is called the *odontogenetic zone* or *predentine*. In it the calcium salts have not been fully deposited, and its superficial

* E. W. Bradford, *Brit. Dental J.*, 90, 303, 1951.

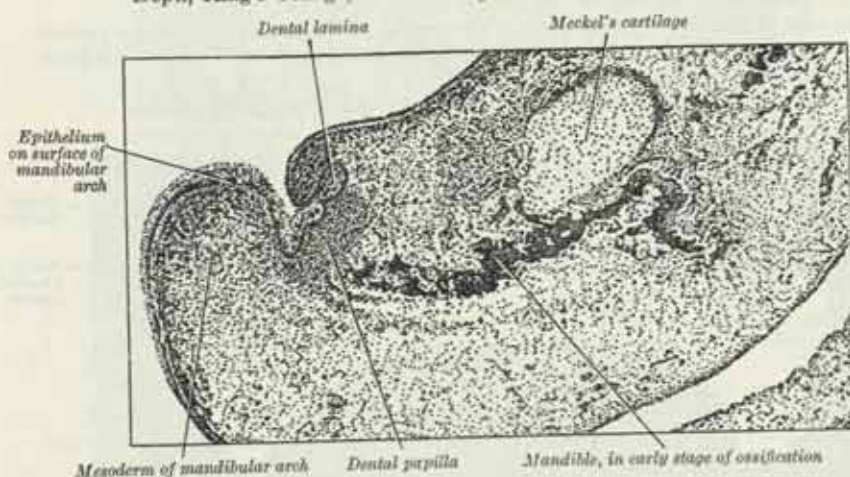
surface is lined by spherical masses of lime salts, through the fusion of which the dentinal matrix is formed. Dentinal tubules, although present, are not so clearly defined in this zone as in the fully developed dentine.

The *enamel* is a dense, white layer forming a crust over the crown of the tooth. It extends as far as the neck, where it meets the cement which covers the root. At the neck, the enamel usually overlaps the cement to a slight extent; sometimes the cement overlaps the enamel, or no overlapping occurs; very rarely the enamel and cement may fail to meet, thus leaving a small area of dentine exposed on the surface of the neck. The enamel is the hardest and most compact part of the tooth. It is thickest over the masticatory surface of the crown until worn down by attrition. It consists almost entirely of inorganic salts, chiefly calcium phosphate. Histologically the enamel consists of minute, beaded, solid rods, called *enamel prisms*, most of which run a more or less parallel course uninterruptedly through the entire thickness of the enamel. They pursue a vertical course on the masticatory surface and a more or less horizontal course at the sides of the crown. Each prism is six-sided (as seen in transverse section), about 4μ in diameter, and presents numerous dark, transverse shadings, which are probably due to the manner in which the prisms are developed in successive stages, shallow constrictions being produced as described below. The prisms have a wavy course, and in alternate layers they often run towards the surface at different angles. Each prism is surrounded by a thin cuticle, which can be deeply stained by Heidenhain's hæmatoxylin. The enamel meets the subjacent dentine along an undulating line (the *amelo-dentinal junction*), the concavities of which are directed towards the enamel. In human teeth, the enamel and dentine do not appear to be intimately united.

When the enamel is worn away in old teeth, the subjacent dentine is exposed and is recognised by its yellowish appearance in contrast with the white enamel. Enamel is devoid of vessels and nerves.

The *cement* forms a thin layer covering the dentine and extends from the neck to the apex of the root. It is thinnest at the neck and increases slightly in thickness towards the apex of the root. There are two kinds of cement, acellular and cellular. The acellular type covers the greater part of the root, whereas the cellular type covers only its apical part. The cellular type resembles bone in structure and chemical composi-

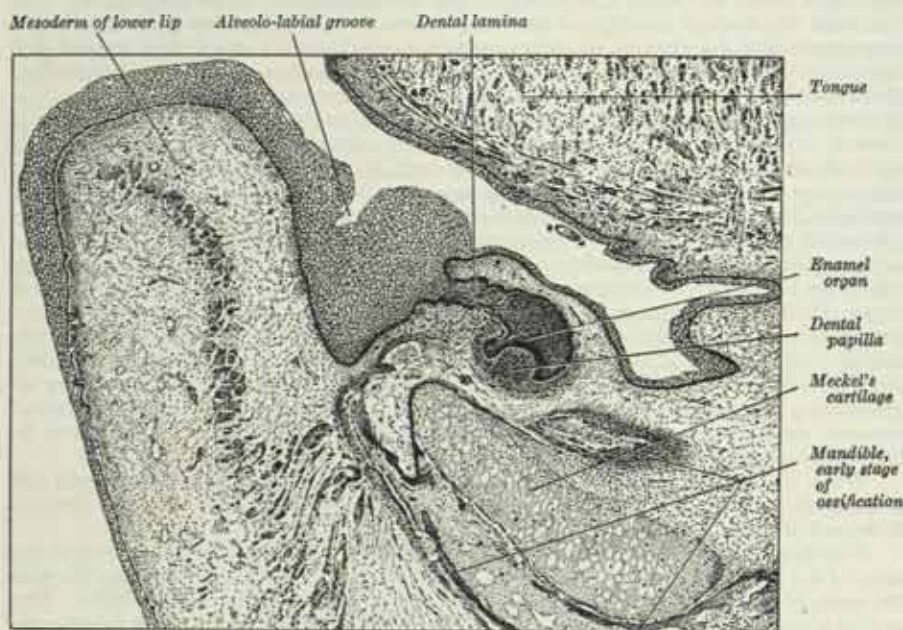
FIG. 1135.—A parasagittal section through the mandibular arch of a 28 mm. C.R. human embryo, passing to the right of the median plane. $\times 50$. Drawn from a photomicrograph kindly given to the Editors by Dr. C. H. Tonge, Anatomy Dept., King's College, Newcastle-upon-Tyne.



tion and contains lacunæ and canaliculi, though the latter are mainly directed towards the periodontal membrane. Perforating fibres of Sharpey pass from the periodontal membrane into canaliculi which penetrate the whole thickness of the cement; in this way the tooth is anchored securely to the alveolar periosteum. The cement is thicker in adult than in young teeth. Normal cement is avascular. Canals resembling Haversian canals of true bone are occasionally present.

Blood-vessels.—The upper molars and premolars receive their arterial blood-supply from the posterior superior alveolar branch of the maxillary artery; the upper canine and incisors from the anterior superior alveolar branches of the infra-orbital artery. The lower teeth are supplied by the inferior alveolar branch of the maxillary

FIG. 1136.—Part of a parasagittal section through the head of a 60 mm. C.R. human embryo, passing through the right lower central incisor tooth germ. Stained with hæmatoxylin and eosin. $\times 12$. Drawn from a photomicrograph kindly given to the Editors by Dr. C. H. Tonge, Anatomy Dept., King's College, Newcastle-upon-Tyne.



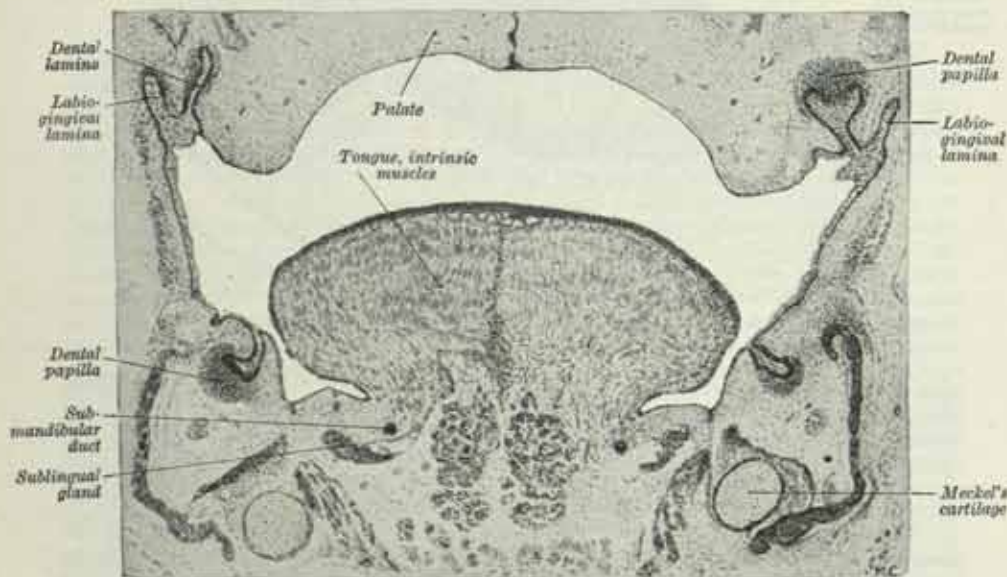
artery. The alveolar periosteum is very vascular. The arteries to the pulp enter it through the foramen at the apex of each root.

The veins accompany the arteries. The lymph vessels are described on p. 889.

Nerves.—The anterior, middle and posterior superior alveolar branches of the maxillary nerve supply the upper teeth, and the inferior alveolar branch of the mandibular nerve the lower teeth (for details see pp. 1104, 1111).

In the case of the lower teeth, there is an overlap in the innervation of the central incisors, the right lower central incisor, for instance, being supplied by branches from

FIG. 1137.—Coronal section of the head of a 34 mm. C.R. human embryo, showing developing teeth.

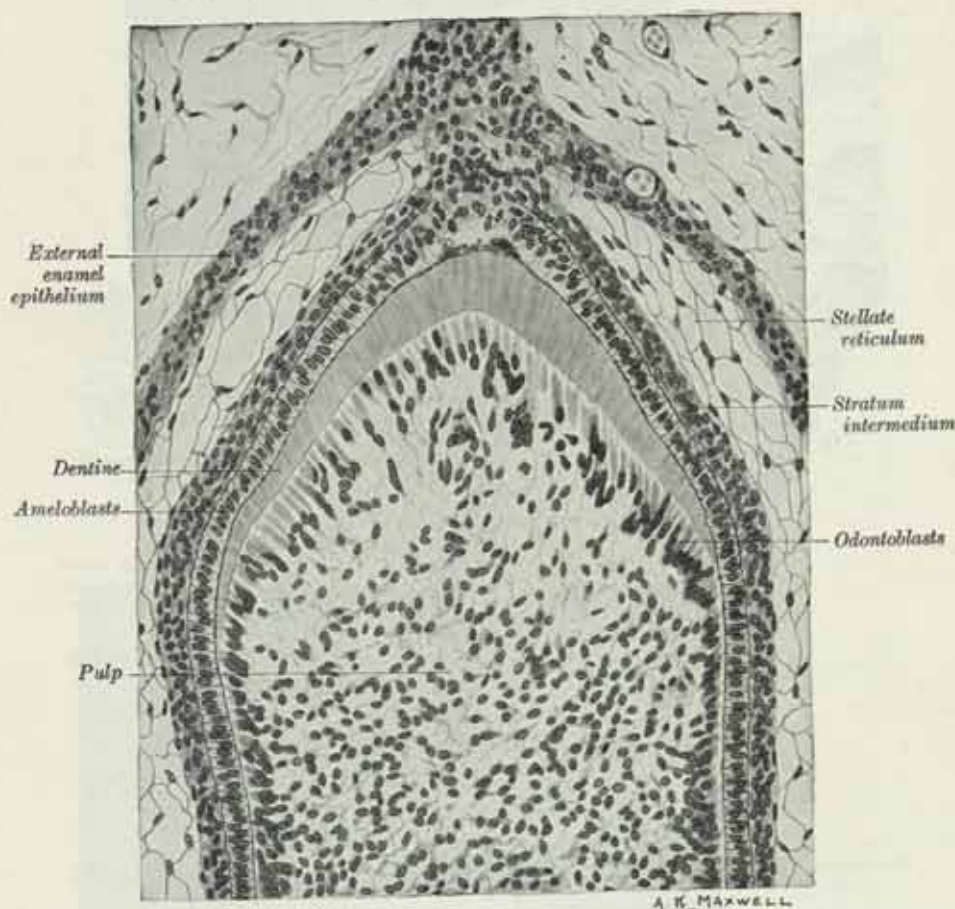


The pointer line to Meckel's cartilage passes through the developing mandible.

the left inferior alveolar nerve in addition to the supply it receives from the nerve of its own side. Further, the lingual and buccal nerves appear to take part in the innervation of the pulp of the lower molars, premolars and canines (Stewart and Wilson *), particularly with respect to the sensation of pain elicited by pin-prick.

The nerve-fibres penetrate from the pulp into the odontogenetic zone of the dentine; some of the finer fibres enter the mouths of the dentinal tubules and penetrate deeply into the calcified dentine.† The application of cold or heat to exposed dentine causes pain. Normally, the covering enamel insulates the dentine efficiently against thermal stimuli.

FIG. 1138.—Developing tooth. Drawing from a photograph.



High power view of part of fig. 1139. Drawn from a photograph by F. Harrison, Dental Department, University of Sheffield, and reproduced, by permission of Messrs. Blackie & Son, Ltd., from *Our Teeth* by Pedley and Harrison.

A rich arborization of nerves is present in the periodontal membrane, but these do not penetrate the cement.

THE DEVELOPMENT OF THE TEETH

Like the skin, teeth are developed from both ectoderm and mesoderm, the enamel being derived from ectoderm, and the other dental tissues (pulp, dentine, cement) from the subjacent mesoderm.

The earliest stage in the formation of the deciduous teeth occurs about the sixth week of intrauterine life, and takes the form of a thickened ridge of epithelium on each of the opposed surfaces of the mandibular arch and maxillary process. This ectodermal ridge is the *primary dental lamina*. On its labial and lingual aspects the mesoderm thickens, thus raising the level of the surface epithelium on either side of the

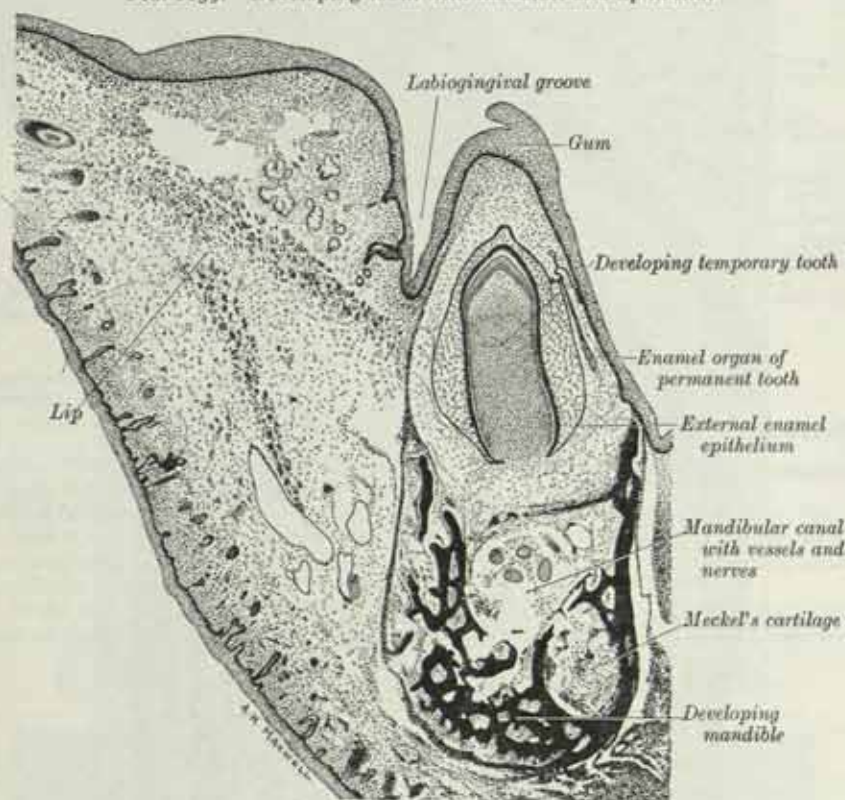
* *J. Anat., Lond.*, 63, 167, 1928.

† R. Cocker and J. M. Hatton, *J. Anat.*, 89, 189, 1955.

lamina, leaving a shallow *dental furrow* overlying the lamina itself, and causing the lamina to project more and more into the surrounding mesoderm (fig. 1135). The deepest part of the primary dental lamina subdivides into two parts, a lateral, termed the *labiokingival lamina*, and a medial, termed the *dentokingival lamina* (or *dental lamina proper* or *common dental germ*). The central cells of the labiokingival lamina later break down and a groove is thus formed. This groove (*alveolo-labial* or *labiokingival groove*, fig. 1136) separates the dental lamina from the outer parts of the mandibular and maxillary processes which give rise to the lips and cheeks; it subsequently enlarges to form the vestibular region of the mouth cavity.

The dental lamina gives rise to the enamel. At first it forms a continuous flat band of cells, but, about the ninth week, five enlargements of the deeper part of the lamina

FIG. 1139.—Developing tooth with mandible and lip *in situ*.



Drawn from a photograph by F. Harrison, Dental Department, University of Sheffield, and reproduced, by permission of Messrs. Blackie & Son, Ltd., from *Our Teeth* by Pedley and Harrison.

occur, each corresponding with a future deciduous tooth, in each of the mandibular and maxillary processes. For a time, these enlargements continue to be connected together by the intervening parts of the original thin dental lamina. These latter disappear later, and the enlargements are then separate and constitute the *enamel organs* or *special dental germs*. Groups of cells of the intervening portions of the lamina may, however, remain; these remnants are known as the 'glands of Serres,' and are thought to be the origin of certain tumours or cysts which sometimes occur in relation to the teeth.

Each enamel organ comes to assume the shape of a club, connected to the surface epithelium by a narrow stalk of ectodermal cells (the unexpanded superficial part of the dental lamina), and its deep surface is invaginated by a papilla of the subjacent mesoderm, named the *dental* (or *dentine*) *papilla*, over which the enamel organ becomes moulded like a hood or cap. This mesodermal papilla assumes the shape of the crown of the future tooth, and gives rise to the pulp and dentine.

From the lingual side of each of the stalks which connect the enamel organs of the deciduous teeth to the surface, a solid ectodermal bud grows into the mesoderm (fig. 1139). This bud is the enamel organ of the permanent tooth (incisors, canines, premolars) which will later replace the appropriate deciduous tooth. It is invaginated by a mesodermal dental papilla in the same manner as described above in the case of

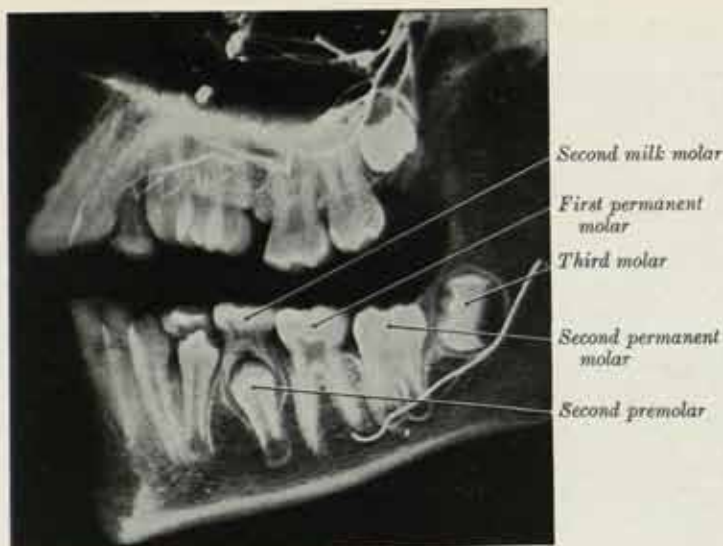


FIG. 1.—Radiograph of the teeth of a girl, 13 years old. (Symington and Rankin's *Atlas of Skiagrams*.)

The roots of the second lower milk molar are in process of being absorbed. Only the crown of the first milk molar remains, and it is ready to be shed. The crown of the third lower permanent molar faces forwards, and its roots have not yet developed. The arteries have been injected.

Note: the eruption of the premolar teeth has been delayed abnormally.

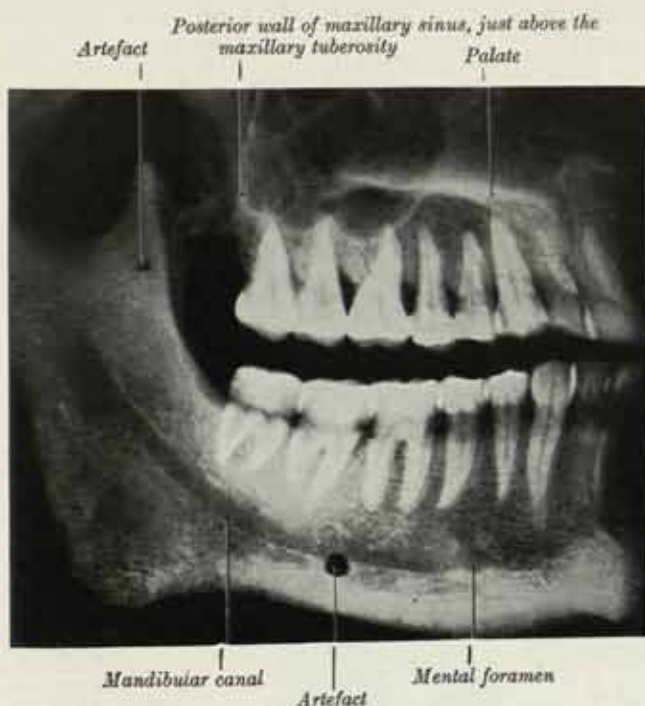


FIG. 2.—Radiograph of the teeth of an adult male skull. Right side. (Symington and Rankin's *Atlas of Skiagrams*.)

Note.—The roots of the upper molars are producing elevations in the floor of the maxillary sinus. The roots of the lower molars (2 and 3) reach almost to the mandibular canal.

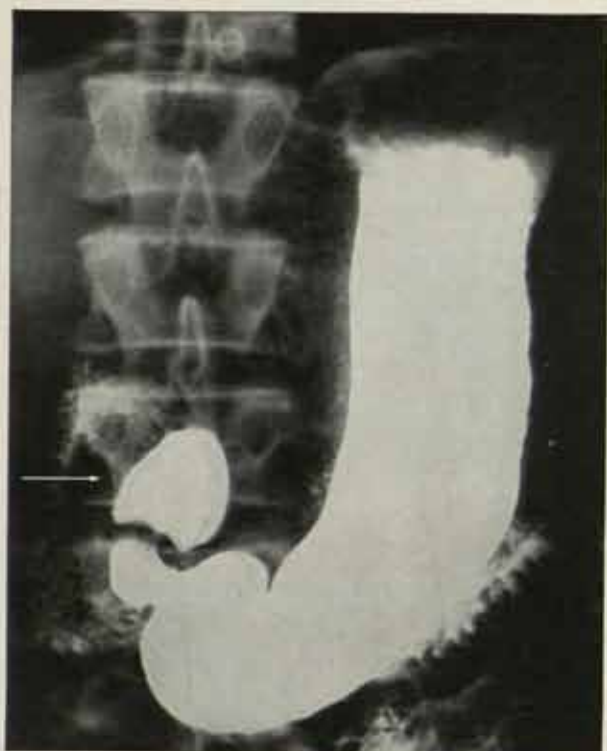


FIG. 1.—Radiograph of a normal stomach after a barium meal. The tone of the muscular wall is good and supports the weight of the column in the body of the organ. The arrow points to the duodenal cap, below which a gap in the barium indicates the position of the pylorus.

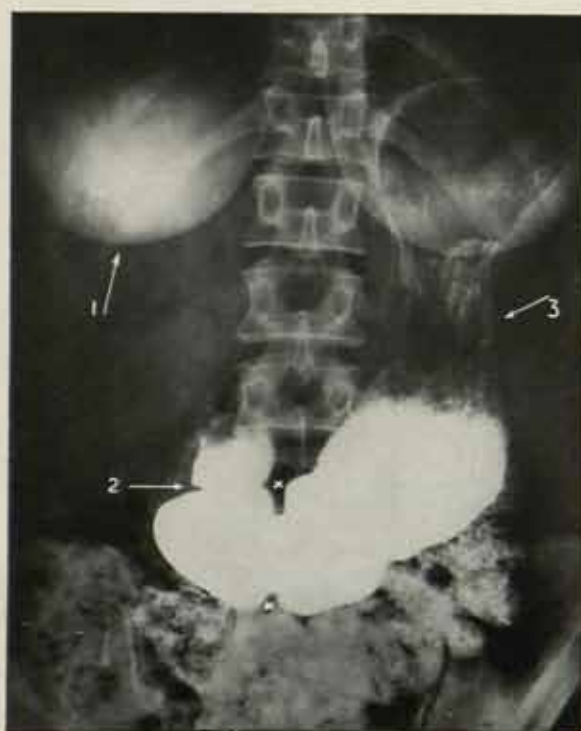


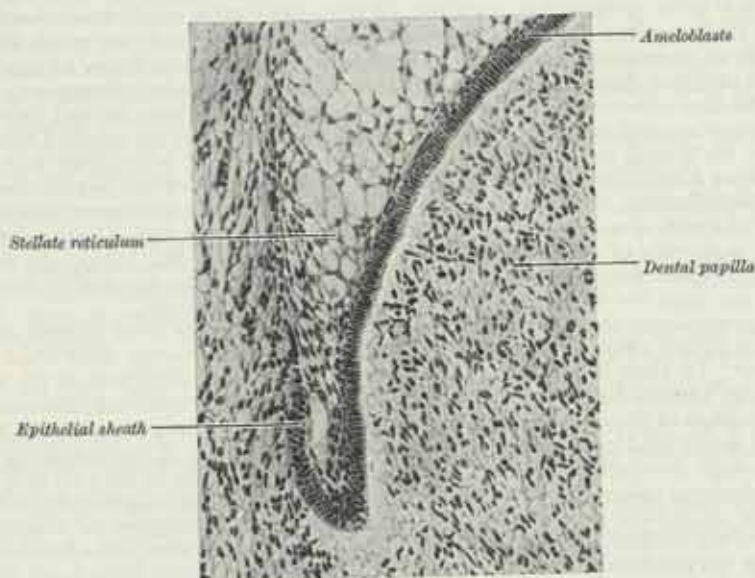
FIG. 2.—Radiograph of an atonic stomach after a barium meal. Note that this stomach contains the same amount of barium as the stomach in fig. 1. Arrow 1 points to the shadow of the right breast; arrow 2, to the pylorus; arrow 3, to the upper part of the body of the stomach, where longitudinal folds can be seen in the mucous membrane. X X marks a wave of peristalsis.

the enamel organs of the deciduous teeth. Those permanent teeth which replace the deciduous teeth are thus developed on the lingual aspect of the latter; the individual pairs of enamel organs (deciduous and permanent) are connected to the surface by a common stalk of ectodermal cells.

While these changes are going on, the dental lamina extends backwards behind the enamel organ of the second deciduous molar tooth. This extension involves only the deeper part of the dental lamina and is therefore not directly connected to the surface epithelium overlying it. About the seventeenth week of intrauterine life, the extension presents an enlargement, which is the enamel organ of the first permanent molar tooth and which soon becomes invaginated by a mesodermal papilla. In the fourth month *after birth* a further extension backwards of the dental lamina occurs, with the formation of another enamel organ and dental papilla for the second molar tooth. This process is repeated for the third permanent molar, the papilla of which appears about the fifth year.

The enamel organs of both the deciduous and permanent teeth consist at first of round or polyhedral epithelial cells. After the formation of the papillæ, these cells undergo a differentiation into four layers. Those in contact with the papilla become elongated, and form a stratum of well-marked columnar epithelium. These cells form the enamel matrix, and are therefore termed *enamel-cells* or *ameloblasts* (fig. 1138).

FIG. 1140.—Longitudinal section of lower part of a growing tooth. $\times c 200$.



The cells of the outer layer of the special dental germ are cubical in form, and are named the *external enamel epithelium* (fig. 1138). The intermediate cells become stellate in shape and form a network into which fluid is secreted; this has the appearance of a jelly, and to it the names of *stellate reticulum* or *enamel-pulp* are given. Between the stellate reticulum and the layer of ameloblasts there is a *stratum intermedium* consisting of two or three layers of round or polygonal cells (fig. 1138).

Around each enamel organ the mesoderm forms a vascular, connective tissue, *dental sac* or *follicle*, which lies in the tooth crypt of the mandible or maxilla. The remains of the dental lamina connecting each enamel organ to the surface epithelium disappears, and each dental sac is connected with the overlying gum by a band of connective tissue, termed the *gubernaculum dentis*, which lies in a gubernacular canal. The gubernacula are short over the developing deciduous teeth; those over the developing permanent teeth are long and, in the case of the incisors, canines and premolars, lie on the lingual aspect of the deciduous teeth.

The formation of enamel (fig. 1138).—The enamel is formed from the ameloblasts of the enamel organ, the process occurring in two phases. In the first, the ameloblasts elongate; their basal parts remain in contact with the newly formed dentine and into them and the spaces between them a primary deposition of calcium salts takes place, the deposition gradually extending outwards. This wave of calcification leads only to a partial impregnation of the matrix. The second phase is one of maturation and results in complete calcification, so that the enamel comes to consist of calcified rods or prisms, surrounded by calcified interprismatic matrix. As these

processes go on, the stellate reticulum and stratum intermedium atrophy and disappear, so that the newly formed calcified enamel and the external enamel-epithelium come into apposition. The crown of the tooth is covered for a time by a distinct membrane, known as the *enamel cuticle* (or Nasmyth's membrane), which is developed from the enamel-epithelium. It forms a horny layer, which may be separated from the subjacent calcified mass by the action of acids, and it is marked by the hexagonal impressions of the enamel prisms and interprismatic substance. While it is normally invisible to the naked eye, its presence is occasionally revealed in children's teeth as a green discolouration due to the action of chromogenic bacteria.

The formation of the dentine.—As before stated, the first germs of the dentine are the papillae, which grow upwards into the enamel-germs and become covered by them, both being enclosed in the dental sacs, in the manner above described. Each papilla then consists of round cells, and is very vascular, and soon begins to assume the shape of the crown of the future tooth. The next step is the appearance of the *odontoblasts*, which are formed from the superficial cells of the papilla; these cells become elongated, one end of the elongated cells resting against the epithelium of the enamel organs, the other being tapered and often branched. The formation of dentine is similar to the process of intramembranous ossification of bone (p. 26) and the odontoblasts play a role like that of the osteoblasts. Through their activity a matrix, containing cork-screw shaped collagen fibres, is laid down between the osteoblasts. This uncalcified matrix is called the *predentine* (or *odontogenetic zone*) and it caps the papilla. In it islets of calcification make their appearance, and, coalescing, give rise to a continuous layer of calcified material, which covers each cusp (underneath the enamel) and constitutes the first layer of dentine. The odontoblasts retire towards the centre of the papilla, and, as they do so, produce successive layers of dentine—that is to say, they form the dentinal matrix in which calcification subsequently takes place. As they recede from the periphery of the papilla, they leave behind them filamentous processes of cell-protoplasm; these are surrounded by the calcified material, and thus the dental canaliculi are formed; the processes of protoplasm contained within these constitute the dentinal fibres. The central part of the papilla does not undergo calcification, but persists as the pulp of the tooth. In certain circumstances, e.g. loss of tooth structure due to caries or attrition, the pulp may be stimulated to renewed formation of dentine (secondary dentine formation, fig. 1133). In certain places uncalcified portions of the matrix remain between the successive layers of dentine, and give rise to the interglobular spaces alluded to above.

The formation of the cement.—The root of the tooth begins to be formed shortly before the crown emerges through the gum; but is not completed until some time afterwards. Its form is determined by a downgrowth of the epithelium of the dental germ which extends below the region where the enamel is to be formed, almost as far as the situation of the apex of the future root; this fold of epithelium is known as the *epithelial sheath* (of Hertwig) (fig. 1140). The vascular tissues of the dental sac then break through the epithelial sheath, and spread over the surface of the root as a layer of bone-forming material. In this layer osteoblasts make their appearance, and the process of ossification goes on as in the intramembranous ossification of bone. The remains of the epithelial sheath may sometimes be seen in the adult as isolated groups of cells in the alveolar periosteum (periodontal membrane).

The formation of the alveoli.—About the fourteenth week of embryonic life the dental lamina is enclosed in a trough or groove of mesodermal tissue, which at first is common to all the dental germs, but subsequently is divided by septa into loculi, each loculus containing the special dental germ of a deciduous tooth and its corresponding permanent tooth. After birth each cavity becomes subdivided, so as to form separate crypts for each deciduous and permanent tooth. Although at one time the whole of the growing tooth is contained in the cavity of the alveolus, the latter never completely encloses it, since there is always an aperture over the top of the crown filled by soft tissue, by which the dental sac is connected with the surface of the gum.

The development of the permanent teeth.—Developmentally considered the permanent teeth may be divided into two sets: (1) the *successional permanent teeth* which replace the deciduous teeth, and, like them, are ten in number in each jaw; and (2) the *superadded permanent teeth* which have no deciduous predecessors, but are developed behind the temporary molars. The superadded permanent teeth are the three permanent molars, the molars of the deciduous set being replaced by the permanent premolars. During their development the successional permanent teeth, enclosed in their sacs, are placed on the lingual side of the deciduous teeth, but are separated from them by bony partitions. As the crown of the permanent tooth grows, absorption of the bony partition and of the root of the deciduous tooth takes place, through the agency of *osteoclasts*, which appear at this time, and finally nothing but the crown of the deciduous tooth remains. This is shed or removed, and the permanent tooth takes its place.

The superadded permanent teeth are developed in the manner already described, by extensions backward of the posterior part of the dental lamina in each jaw (p. 1369).

The eruption of the teeth.—When the calcification of the different tissues of the tooth is sufficiently advanced to enable it to bear the pressure to which it will be subjected, eruption takes place, the tooth making its way through the gum. The eruption of the deciduous teeth commences about the sixth month after birth, and is completed about the end of the second year, the teeth of the lower jaw preceding those of the upper (Pl. XXIV and figs. 1141 and 1142).

C. S. Tomes gave the following as the most usual times of eruption of the deciduous teeth:

Lower central incisors	6 to 9 months
Upper incisors	8 to 10 months
Lateral incisors and first molars	15 to 21 months
Canines	16 to 20 months
Second molars	20 to 24 months

There are, however, considerable variations in these times. According to Holt: a child at the age of one year should have six teeth; at the age of a year and a half, twelve; at the age of two years, sixteen; and at the age of two and a half years, twenty.

Calcification of the permanent teeth proceeds in the following order in the lower jaw (in the upper jaw it takes place a little later): the first molars, at birth; the incisors and canines, about six months after birth; the premolars, at the third year, or a little later; the second molars, about the end of the fourth year; the third molars, about the eighth year.

The eruption of the permanent teeth takes place at the following periods, the teeth of the lower jaw preceding those of the upper by short intervals:

First molars	6th year
Central incisors	7th year
Lateral incisors	8th year
First premolars	9th year
Second premolars	10th year
Canines	11th to 12th year
Second molars	12th to 13th year
Third molars	17th to 25th year

Towards the sixth year, before any of the deciduous teeth are shed, there are twenty-four teeth in each jaw, viz. the ten deciduous teeth and the crowns of all the permanent teeth except the third molars (fig. 1141).

It should be noted that the first molars are the earliest of the permanent teeth to erupt (fig. 1142). This arrangement provides for the satisfactory mastication of food during the period when the premolars are erupting and the milk molars, which are in process of being shed, are of little value for this purpose. It is of interest to observe that in the eruption of both the deciduous and the permanent teeth, the canine appears in the interval between two teeth which have already erupted.

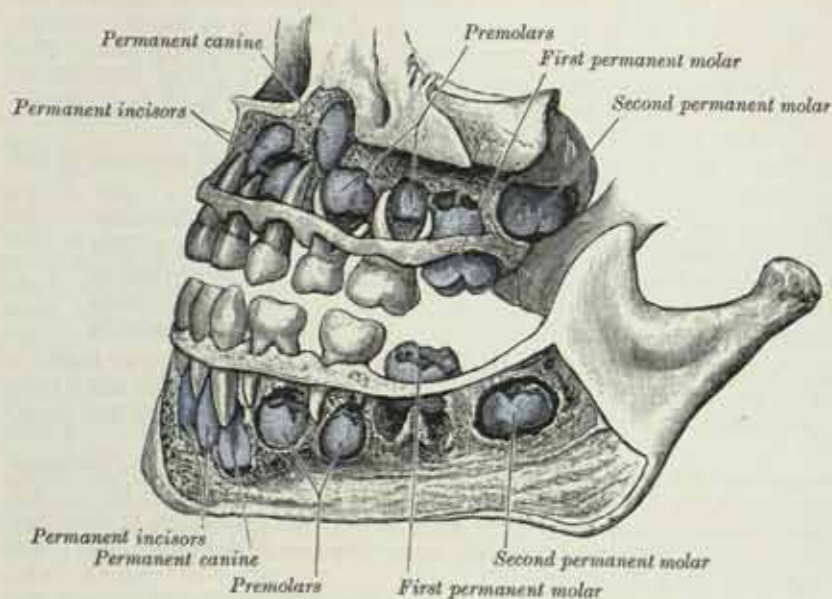
The precise mechanism of eruption of the teeth is unknown. Probably several factors are involved, such as unequal rates of growth of the tissues surrounding the teeth, elongation of the roots and deposition of bone in the alveolar sockets, although there are objections to each of these, e.g. a tooth may fail to erupt even if the root is fully developed and teeth with stunted roots may erupt. The site of eruption is determined by the dental lamina and gubernaculum dentis which extend from the gum to the enamel organs and which by atrophy provide a 'path of least resistance' for the erupting tooth.

*Development of the gums.**—The gum is developed in two parts. The *labiobuccal part* lies between the lip-groove and the dental groove. It appears before the lingual part, grows more rapidly, and is the more prominent; it takes the chief share in the formation of the adult gum, and becomes divided into segments which correspond in size and number with the tooth-sacs. The *lingual part* is not segmented, and its surface remains almost entirely smooth. The tissue of the gum in advance of the tooth is highly vascular, and furnishes a source of nutrition for the developing tooth.

Applied Anatomy.—As a consequence of diseases such as the acute infective fevers, which cause a temporary diminution in the calcium content of the blood, both the

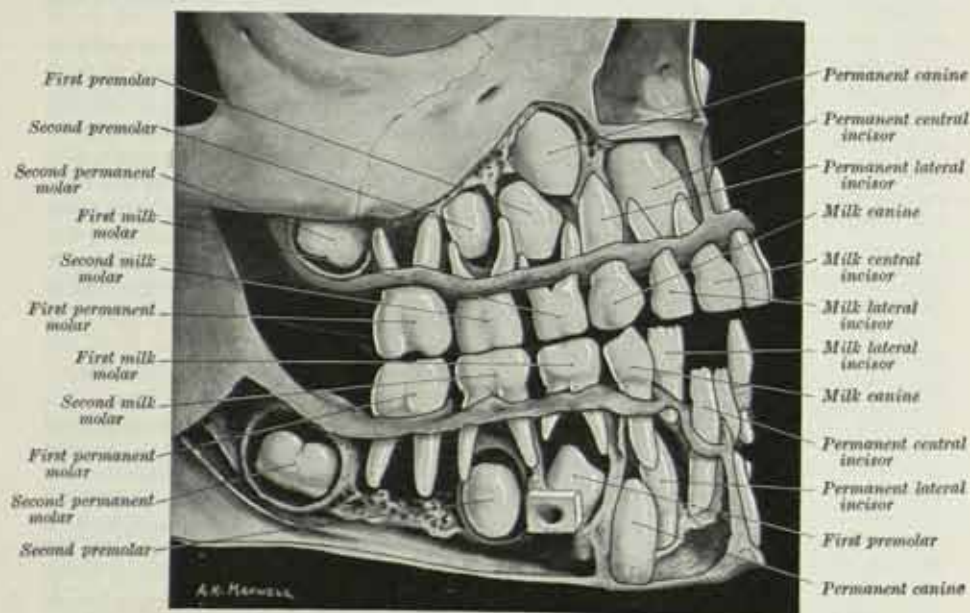
* Cecil M. West, *Contrib. Embryol.*, 16, 1925.

FIG. 1141.—The teeth of a child about six years. The permanent teeth are coloured blue.



deciduous and the permanent teeth may show defective development or irregular transverse furrows and erosions; this is particularly the case with the incisors. A characteristic malformation of the two upper central permanent incisors is seen in patients with inherited syphilis, and was first described by Hutchinson. Here there is a crescentic notch in the anterior surface and at the cutting edge of the tooth, which is peg-shaped, stunted, and set obliquely in the gum, pointing either medially or laterally. The roots of the first and second upper permanent molar teeth produce eminences on

FIG. 1142.—Normal dentition of a child aged 7 years. The first permanent molars, both upper and lower, have erupted, and the permanent lower central incisors are in process of erupting, the milk lower central incisors having been shed.

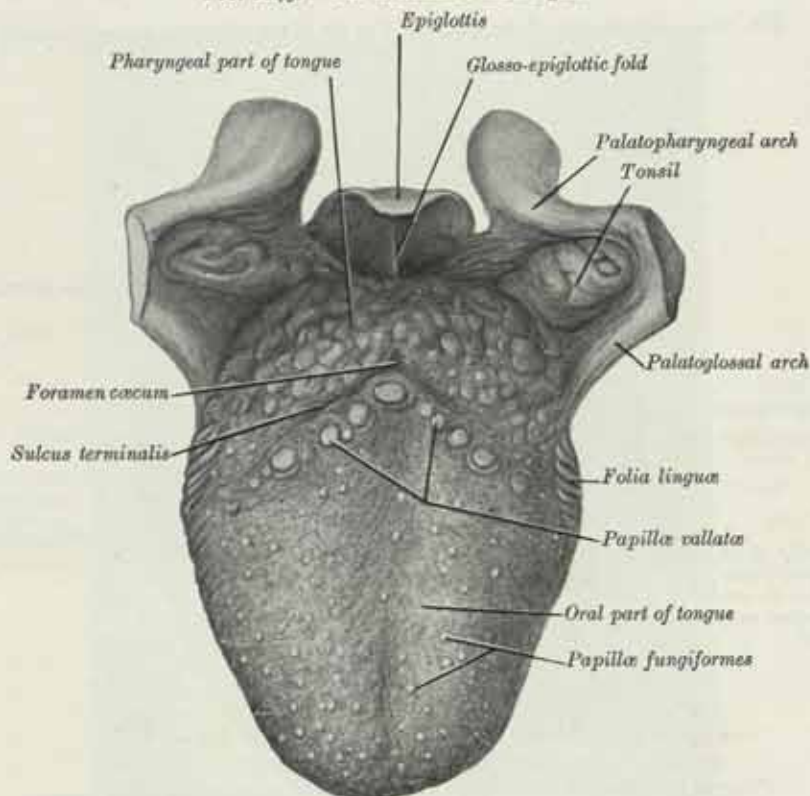


Drawn from a photograph by F. Harrison, Dental Department, University of Sheffield, and reproduced, by permission of Messrs. Blackie & Son, Ltd., from *Our Teeth* by Pedley and Harrison.

the floor of the maxillary sinus, and the thin layer of bone between the alveoli for these teeth and the sinus may sometimes be deficient, only mucous membrane of the sinus separating the teeth from the cavity of the sinus. Infection of these teeth can thus easily spread to the sinus, and, in extraction of these teeth, the soft tissues may be torn and the sinus thus made to communicate with the mouth cavity through the alveoli. The upper teeth whose roots are in relation with the sinus range from the first and second molars as a minimum to all the teeth, *excluding the incisors*, as a maximum (see p. 1233).

Radiology of the Teeth (Plates XXIV and XXV).—Normal dentine, enamel and cement are opaque to X-rays and therefore appear as dense shadows. The pulp is translucent and appears as a clear area in the crown, neck and roots of the teeth. The

FIG. 1143.—The dorsum of the tongue.



interalveolar bony septa, and the walls of the alveoli normally show the characteristic pattern of the bony lamellæ; this pattern is destroyed by abscesses or infection of the bone and of the tooth sockets.

THE TONGUE [LINGUA] (figs. 1143 to 1145)

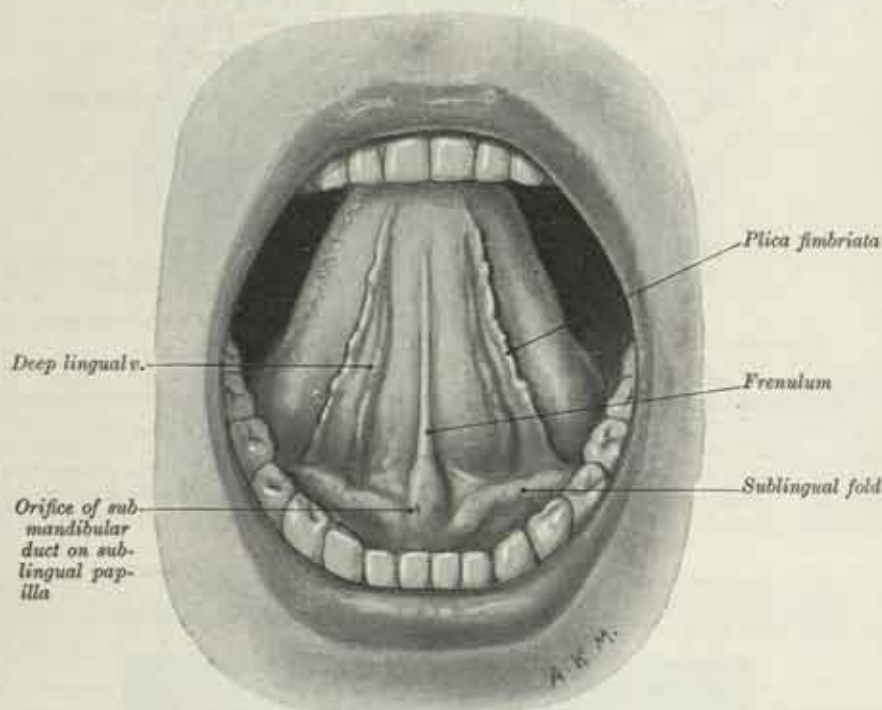
The **tongue** is a muscular organ intimately associated with the functions of taste, speech and deglutition; it is situated partly in the mouth, and partly in the pharynx. By its constituent muscles it is attached to the hyoid bone, the mandible, the styloid processes, the soft palate and the wall of the pharynx. It possesses a root, a tip, a curved dorsum and an inferior surface. Normally, the mucous membrane on its upper surface is moist and pink.

The **root** of the tongue (fig. 1112) is attached to the hyoid bone and the mandible, and between these bones is in contact inferiorly with the Geniohyoid and the Mylohyoid muscles. The **dorsum** (or upper surface) is convex from before backwards, and from side to side, and is divided into an anterior part which faces upwards, and a posterior part which faces backwards. These two parts are separated by a V-shaped furrow, termed the *sulcus terminalis*, the limbs of which run laterally and forwards from a median pit, named the *foramen cæcum*, to the palatoglossal arches (fig. 1143). The foramen cæcum marks the site of the upper end of the thyroid diverticulum (p. 184), and the sulcus terminalis serves as the boundary

between the oral part or anterior two-thirds, and the pharyngeal part or posterior one-third, of the tongue. These two parts differ in the structure of their covering mucous membrane, in their nerve-supply and in their development (p. 184).

The *oral part* of the tongue (figs. 1143, 1144) is placed in the cavity and floor of the mouth; its *apex* rests against the incisor teeth; its *margin* is free and in contact with the gums and teeth; its *superior surface* is in relation with the hard and soft palates. On each border, just in front of the palatoglossal arch, there are four or five vertical folds, named the *folia linguae* (fig. 1143), which correspond to the papillae foliatae of the rabbit's tongue. The mucous membrane of the superior surface of the oral part is marked by a median furrow (figs. 1143, 1145), is intimately adherent to the subjacent muscle, and is covered with papillae. The mucous membrane on the

FIG. 1144.—The cavity of the mouth. The tip of the tongue is turned upwards.



Note.—In the model from whom the drawing was made the two sublingual papillae formed a single median elevation.

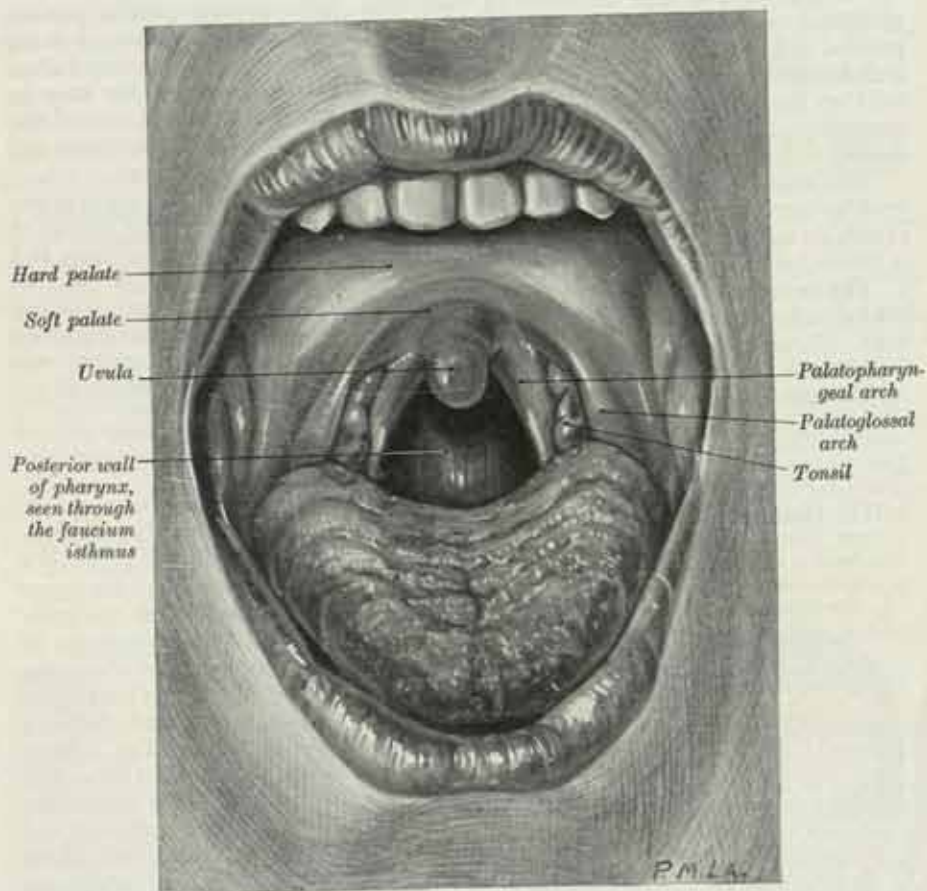
inferior surface is smooth, and of a purplish colour; it is reflected from the tongue to the floor of the mouth and the gums. In the median plane it is connected to the floor of the mouth by the frenulum linguae (fig. 1144). Lateral to the frenulum, the deep lingual vein is seen shining through the mucous membrane, and at the lateral side of the vein there is a fringed fold of mucous membrane, named the *plica fimbriata*, which is directed forwards and medially towards the apex. The oral part of the tongue is developed from the lingual swellings of the mandibular arch, and to a small extent from the tuberculum impar (p. 182). Its nerve of ordinary sensation is the lingual; its nerve of taste, the chorda tympani.

The *pharyngeal part* of the tongue (fig. 1143) lies behind the palatoglossal arches and the oropharyngeal isthmus; its posterior surface (sometimes named the *base* of the tongue) forms the anterior wall of the oral part of the pharynx. The mucous membrane covering it is reflected laterally on to the tonsils and the pharyngeal wall, and posteriorly on to the epiglottis, where it forms a median glosso-epiglottic fold, and two lateral glosso-epiglottic folds. It is devoid of papillae, but exhibits a number of low elevations, due to the presence of underlying nodules of lymphoid tissue, which are imbedded in the submucous tissue and collectively constitute the *lingual tonsil*. The pharyngeal part of the tongue is developed from the hypo-branchial eminence, which is described on p. 183. Its nerves of ordinary sensation

and of taste are derived from the glossopharyngeal. The branches of the glossopharyngeal nerve extend beyond the sulcus terminalis to supply taste fibres to the vallate papillae, an arrangement which is explained by the forward extension of the part of the hypobranchial eminence derived from the third pharyngeal arch over the posterior part of the lingual swellings (p. 183).

The *papillae of the tongue* (fig. 1143) are projections of the corium. They are thickly distributed over the anterior two-thirds of the dorsum, giving to this part its characteristic roughness. They are grouped under the terms *papillae vallatae*, *papillae fungiformes*, *papillae filiformes* and *papillae simplices*. Whereas the *papillae* are limited to the anterior two-thirds of the tongue and are modifications of the

FIG. 1145.—The cavity of the mouth.



mucous membrane visible to the naked eye and designed to increase the area of mucous membrane coming into contact with the fluid which is being tasted, the taste-buds (p. 1223) are microscopic, specialised cellular arrangements about the endings of the nerves of taste and are much more widespread than the papillae (e.g. entire dorsum and sides of tongue, epiglottis and under surface of the soft palate); each of these regions will therefore be innervated by the appropriate nerve of taste (facial, glossopharyngeal, or vagus). The papillae are more readily visible in the living if the tongue be first dried by applying blotting paper or a handkerchief.

The *vallate papillae* (fig. 1143) are of large size, and vary from eight to twelve in number. They are situated on the dorsum of the tongue, and form a V-shaped row immediately in front of and parallel with the sulcus terminalis. Each papilla is from 1 mm. to 2 mm. in diameter, and is attached within a circular depression of the mucous membrane; each depression is surrounded by a wall (vallum) separated from the papilla by a circular sulcus (fig. 1146). The papilla is shaped like a truncated cone, the smaller end being attached to the tongue; the broader end projects a little

above the surface of the tongue, and is studded with numerous small secondary (dermal) papillæ subjacent to the epithelial layer. The entire papilla and the surrounding sulcus are covered with stratified squamous epithelium.

The *fungiform papillæ* (fig. 1143, 1148), more numerous than the preceding, are found chiefly at the sides and apex of the tongue, but are usually scattered irregularly and sparingly over the dorsum, though sometimes they may be numerous. They are easily distinguished from the filiform papillæ by their large size, round shape, and deep red colour; each exhibits secondary papillæ beneath the epithelium. On the sides of the tongue they are somewhat flattened.

The *filiform papillæ* (fig. 1148) cover the anterior two-thirds of the dorsum of the tongue. They are very minute, conical or cylindrical in shape, and arranged in rows which run parallel with those of the vallate papillæ, excepting at the apex of the tongue, where their direction is transverse. The filiform papillæ present numerous, secondary, connective tissue (dermal) papillæ, but these are more pointed and contain a larger proportion of elastic fibres than the secondary vallate and fungiform papillæ. The epithelium covering the filiform papillæ may be split up into filamentous processes, each of which forms the apex of one of the secondary papillæ; these processes are of a whitish tint, owing to the thickness and density of the epithelium, the cells of which are elongated and cornified.

The *papillæ simplices* are similar to those of the skin, and cover the whole of the mucous membrane of the tongue, as well as the larger papillæ. They consist of closely set microscopic elevations of the corium; each contains a capillary loop, and is covered with epithelium.

The muscles of the tongue (fig. 1147).—The tongue is divided into right and left halves by a median fibrous septum, which is fixed below to the body of the hyoid bone. In each half there are two sets of muscles, extrinsic and intrinsic; the former have their origins outside the tongue, the latter are contained within it.

The *extrinsic muscles* (fig. 1149) are:

Genioglossus.

Hyoglossus.

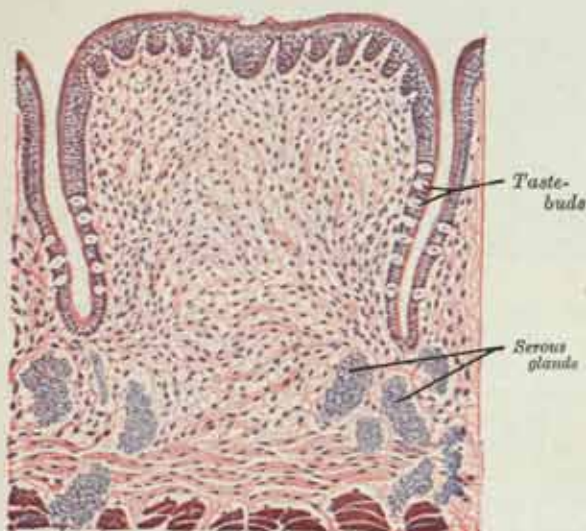
Chondroglossus.

Styloglossus.

Palatoglossus.*

The **Genioglossus** is a triangular muscle placed close to and parallel with the

FIG. 1146.—Section through a vallate papilla. Stained with hæmatoxylin and eosin. $\times 625$. (After Sobotta.)



median plane. It arises by a short tendon from the upper genial tubercle on the inner surface of the symphysis of the mandible, just above the origin of the Geniohyoid muscle, and spreads out in a fan-like form. The inferior fibres are attached by a thin aponeurosis to the upper part of the anterior surface of the body of the hyoid bone, close to the midline, a few passing between the Hyoglossus and Chondroglossus to blend with the Middle constrictor of the pharynx; the middle fibres pass backwards, and the superior ones upwards and forwards, to enter the whole length of the under surface of the tongue, from the root to the apex, intermingling with the intrinsic

muscles. The muscles of opposite sides are separated posteriorly by the septum of the tongue (p. 1380); in front, they are more or less blended owing to the decussation of fasciculi in the median plane.

* The Palatoglossus, although one of the muscles of the tongue, is more closely associated with the soft palate in situation, function and nerve-supply; it is consequently described with the muscles of that structure (p. 1348).

Actions.—The Genioglossus draws the tongue forwards and protrudes the tip from the mouth. The two muscles acting in their entirety draw the median part of the tongue downwards so as to make the superior surface concave from side to side.

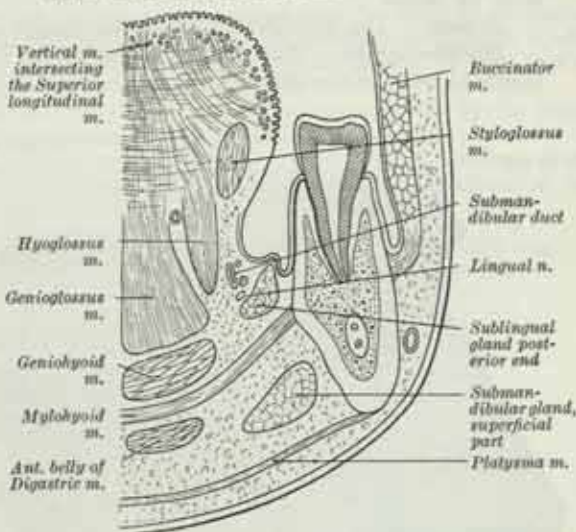
The **Hyoglossus**, thin and quadrilateral, arises from the whole length of the greater horn, and from the front of the lateral part of the body, of the hyoid bone; it passes almost vertically upwards and enters the side of the tongue, between the Styloglossus, laterally, and the Inferior longitudinal muscle, medially. The fibres arising from the body of the hyoid bone overlap those from the greater horn.

Relations.—The Hyoglossus is in relation by its *superficial surface* with the tendon of the Digastric, the Stylohyoid, Styloglossus and Mylohyoid muscles, the lingual nerve and the submandibular ganglion, the sublingual gland, the deep portion of the submandibular gland and the submandibular duct, the hypoglossal nerve and the deep lingual vein. By its *deep surface* it is in relation with the stylohyoid ligament, the Genioglossus, the Inferior longitudinal muscle, the lingual artery and the glossopharyngeal nerve. In its lower and posterior part, it is separated from the Middle constrictor of the pharynx by the lingual artery. This portion of the muscle lies in the lateral wall of the pharynx, a little below the tonsil. The following structures pass deep to the posterior border of the muscle, in order from above downwards: the glossopharyngeal nerve, the stylohyoid ligament and the lingual artery.

FIG. 1148.—Section through a filiform papilla and an adjoining fungiform papilla. Stained with hæmatoxylin and eosin. $\times 6, 20$. (Drawn from a preparation kindly lent to the Editors by Dr. E. E. Hewer.)



FIG. 1147.—Diagram of a coronal section through the tongue, the mouth and the body of the mandible opposite the first molar tooth.



Action.—The Hyoglossus depresses the tongue.

The **Chondroglossus** is sometimes described as a part of the Hyoglossus, but it is separated from that muscle by fibres of the Genioglossus which pass to the side of the pharynx. It is about 2 cm. long, and arises from the medial side and base of the lesser horn and contiguous portion of the body of the hyoid bone; it ascends and blends with the intrinsic muscular fibres of the tongue, between the Hyoglossus and Genioglossus.

A small slip arises occasionally from the cartilago triticea in the lateral thyrohyoid ligament and enters the tongue with the posterior fibres of the Hyoglossus.

Action.—The Chondroglossus assists the Hyoglossus in depressing the tongue.

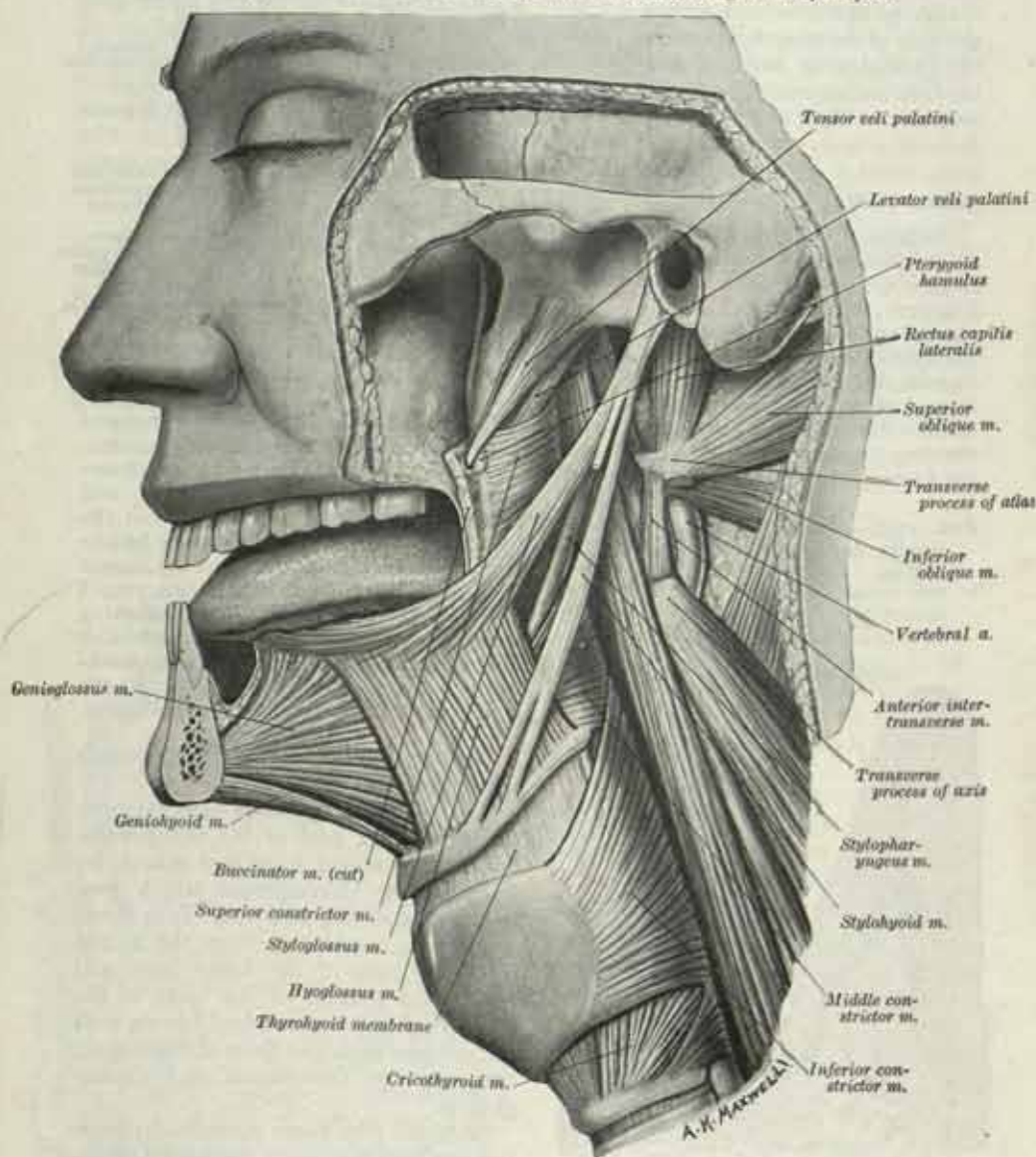
The **Styloglossus**, the shortest and smallest of the three styloid muscles, arises from the anterior and lateral sur-

faces of the styloid process, near its apex, and from the upper end of the stylo-mandibular ligament. Passing downwards and forwards, it divides upon the side of the tongue into two portions; one, longitudinal, enters the side of the tongue near its dorsal surface, blending with the fibres of the Inferior longitudinal muscle in front of the Hyoglossus; the other, oblique, overlaps the Hyoglossus and decussates with its fibres.

Action.—The Styloglossus draws the tongue upwards and backwards.

Nerve-supply.—With the exception of the Palatoglossus (p. 1348) all the extrinsic muscles of the tongue are supplied by the hypoglossal nerve.

FIG. 1149.—A dissection showing the muscles of the tongue and pharynx.



The *intrinsic muscles* are the Superior and Inferior longitudinal, the Transverse and the Vertical muscles.

The **Superior longitudinal muscle of the tongue** is a thin stratum of oblique and longitudinal fibres immediately underlying the mucous membrane on the dorsum of the tongue. It arises from the submucous fibrous layer close to the epiglottis, and from the median fibrous septum, and runs forward to the edges of the tongue, some of its fibres being inserted into the mucous membrane.

The **Inferior longitudinal muscle of the tongue** is a narrow band situated on the under surface of the tongue between the Genioglossus and Hyoglossus. It extends from the root to the apex of the tongue, some of its posterior fibres being connected with the body of the hyoid bone; in front it blends with the fibres of the Styloglossus.

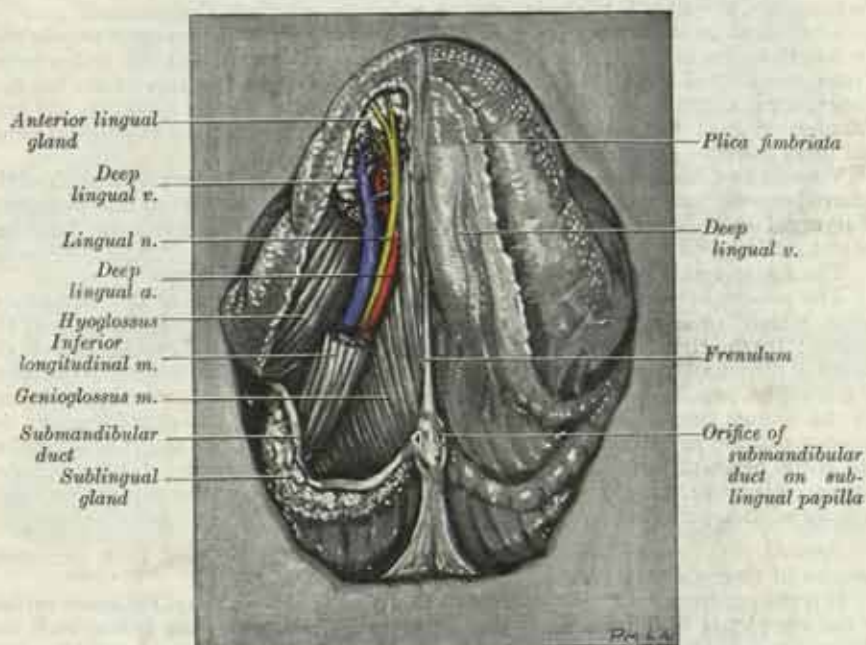
The **Transverse muscle of the tongue** consists of fibres which arise from the median fibrous septum and pass laterally to be inserted into the submucous fibrous tissue at the sides of the tongue, and to blend with the Palatopharyngeus (p. 1348).

The **Vertical muscle of the tongue** is found at the borders of the fore part of the tongue. Its fibres extend from the upper to the under surface of the organ.

Nerve-supply.—The intrinsic muscles of the tongue are supplied by the hypoglossal nerve.

Actions.—The intrinsic muscles are mainly concerned in altering the shape of the tongue; thus, the Superior and Inferior longitudinal muscles tend to shorten it, but

FIG. 1150.—A dissection of the under surface of the tongue. On the right side (left side of figure) the mucous membrane has been removed, and the Inferior longitudinal muscle has been divided and partially resected.



the former, in addition, turns the tip and sides upwards so as to render the dorsum concave, while the latter pulls the tip downwards and renders the dorsum convex. The Transverse muscle narrows and elongates the tongue, and the Vertical muscle flattens and broadens it. Movements of the tongue are concerned in speech, mastication and deglutition.

Structure of the tongue.—The tongue consists chiefly of striated muscular tissue, but is partly invested by mucous membrane and a submucous fibrous layer.

The mucous membrane covering the under surface of the tongue is thin, smooth, and identical in structure with that lining the rest of the oral cavity. The mucous membrane of the pharyngeal part of the dorsum of the tongue is thick and freely movable over the subjacent parts. It contains a large number of follicles of lymphoid tissue; each follicle forms a rounded eminence, in the centre of which there is a minute orifice leading into a funnel-shaped cavity or recess; numerous round or oval nodules of lymphoid tissue, each enveloped by a capsule derived from the submucous fibrous layer, are grouped around this recess, which receives the openings of the ducts of some mucous glands in its floor. The mucous membrane on the oral part of the dorsum of the tongue is thin, intimately adherent to the muscular tissue, and covered with numerous papillæ (p. 1375). It consists of a layer of connective tissue (the corium) covered with epithelium.

The epithelium is of the stratified squamous variety, similar to, but much thinner and less complex than that of the skin; it invests each papilla from root to summit.

The *corium* consists of a dense felt-work of fibrous connective tissue, with numerous elastic fibres, firmly united with the fibrous tissue between the muscular bundles of the tongue. It contains the ramifications of the numerous vessels and nerves from which the papillæ are supplied, large plexuses of lymph vessels and the glands of the tongue.

Glands of the tongue.—The tongue is provided with mucous and serous glands.

The *mucous glands* are similar in structure to the labial and buccal glands. They are numerous in the posterior one-third of the tongue, i.e. behind the vallate papillæ, but are also present at the tip and margins. In this connexion the *anterior lingual glands* require special notice. They are situated on the under surface of the tip of the tongue (fig. 1150), one on each side of the frenulum, where they are covered by the mucous membrane and by a fasciculus of muscular fibres derived from the Styloglossus and Inferior longitudinal muscles. They are from 12 mm. to 20 mm. long, and about 8 mm. broad; each consists of mucous and serous alveoli, and opens by three or four ducts on the under surface of the tip of the tongue.

The *serous glands* occur in the neighbourhood of the taste-buds, their ducts opening for the most part into the sulci of the vallate papillæ (fig. 1146). These glands are racemose; the duct of each branches into several minute ducts, which end in alveoli lined by a single layer of columnar or polygonal epithelium. Their secretion is of a watery nature, and probably assists in distributing the substance to be tasted over the taste area, as well as in washing away the substance after it has been tasted.

The *septum* of the tongue is a median fibrous partition which extends throughout the length of the organ, but does not quite reach the dorsum; it gives origin to the Transverse lingual muscle, and is well displayed in a coronal section of the tongue. Posteriorly it expands in a transverse direction and forms what is known as the *hyoglossal membrane*; this membrane connects the root of the tongue to the hyoid bone, and gives insertion to the inferior fibres of the Genioglossi.

Vessels and Nerves.—The main *artery* of the tongue is the lingual branch of the external carotid artery (p. 740), but the tonsillar branch of the facial and ascending pharyngeal arteries also give branches to the root of the organ. The *veins* are described on p. 842.

The *lymph vessels of the tongue* are described on pp. 889, 891.

The *sensory nerves of the tongue* are: (1) the lingual branch of the mandibular nerve, which is the nerve of ordinary sensibility for the anterior two-thirds of the tongue; (2) the chorda tympani branch of the facial nerve (p. 1118), which runs in the sheath of the lingual nerve, and is the nerve of taste for the anterior two-thirds exclusive of the vallate papillæ (p. 1375); this nerve is derived from the nervus intermedius; (3) the lingual branch of the glossopharyngeal nerve, which is distributed to the mucous membrane at the base and sides of the tongue, and to the vallate papillæ, and is the nerve of taste and of general sensibility for this region; (4) the superior laryngeal nerve (p. 1133), which sends some fine branches to the part immediately in front of the epiglottis.

Applied Anatomy.—Congenital cysts and fistulæ may develop from persistent remains of thyroglossal duct (p. 184).

It is the attachment of the Genioglossi to the genial tubercles on the inner surface of the symphysis of the mandible which prevents the tongue from falling back and obstructing respiration, and, therefore, anæsthetists pull forward the mandible to get the full benefit of this connexion.

THE ISTHMUS FAUCIUM (OROPHARYNGEAL ISTHMUS) (fig. 1145)

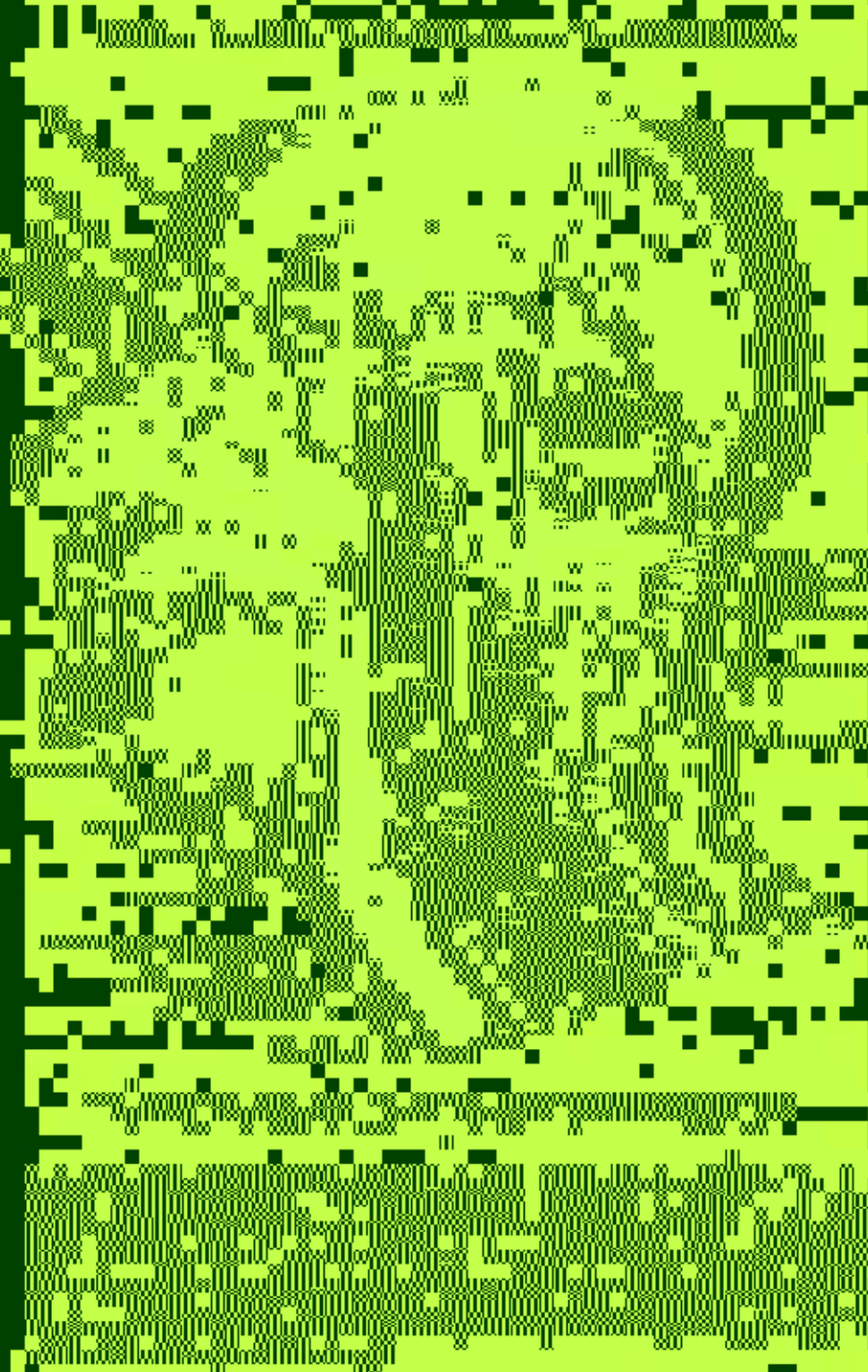
The aperture by which the mouth communicates with the pharynx is called the *isthmus faucium*. Above, it is bounded by the soft palate; below, by the dorsum of the tongue; and, at the sides, by the palatoglossal arches.

The *palatoglossal arch* runs downwards, laterally and forwards on each side from the inferior surface of the soft palate to the side of the tongue, and is formed by the projection of the Palatoglossus (p. 1348) with its covering mucous membrane. The approximation of the arches, which helps to shut off the mouth from the oral part of the pharynx, plays an important part in the mechanism of deglutition (p. 1390).

THE PHARYNX (figs. 1151–1157)

The **pharynx** is the part of the digestive tube which is placed behind the nasal cavities, the mouth and the larynx. It is a musculomembranous tube, from 12 to 14 cm. long, which extends from the under surface of the skull to the sixth cervical vertebra opposite the lower border of the cricoid cartilage. Its width is greatest at its uppermost part, where it measures 3.5 cm.; at the junction of the pharynx with

the œsophagus it is reduced to about 1.5 cm., this being the narrowest part of the alimentary canal (constriction of the œsophagus). The pharynx is the common



The **nasal part of the pharynx** * lies behind the nose and above the level of the soft palate. With the exception of the soft palate its walls are immovable, and consequently its cavity is never obliterated; in this respect it differs from the oral and laryngeal parts, and resembles the nasal cavities. *In front* (fig. 1151) it communicates with the nasal cavity through the posterior apertures of the nose; these measure about 25 mm. vertically, and 12.5 mm. transversely, and are separated by the posterior edge of the nasal septum. Between the free edge of the soft palate and the posterior wall of the pharynx the nasal and oral parts of the pharynx communicate through an opening, termed the *pharyngeal isthmus*; in the act of swallowing this opening is closed by the elevation of the soft palate and the contraction of the Palatopharyngeal sphincter (p. 1389). The *lateral wall*, on each side, presents the *pharyngeal opening of the auditory tube*, which lies 1.0 cm. to 1.25 cm. behind and a little below the posterior end of the inferior nasal concha. Somewhat triangular in shape, this opening is bounded above and behind by the *tubal elevation*, a firm prominence which is provided by the underlying pharyngeal end of the cartilage of the auditory tube (p. 1275). The prominent posterior margin facilitates the introduction into the tube of a catheter which has been passed through the nares and along the floor of the nasal cavity. A vertical fold of mucous membrane, termed the *salpingopharyngeal fold*, stretches from the lower part of the tubal elevation downwards to the wall of the pharynx; it contains the *Salpingopharyngeus* muscle. A second and smaller fold, termed the *salpingopalatine fold*, stretches from the upper and front part of the elevation to the palate. The Levator veli palatini, as it enters the soft palate, produces an elevation of the mucous membrane immediately below the pharyngeal opening of the tube (fig. 1155). Behind the tubal elevation the mucous membrane lines a recess of variable depth, termed the *pharyngeal recess*. The *roof* and *posterior wall* form a continuous sloping surface which inclines downwards and backwards. It is supported mainly by the basilar part of the occipital bone and, to a lesser extent, by the posterior part of the body of the sphenoid, in front, and the anterior arch of the atlas, below. A collection of lymphoid tissue, best developed in children, lies in the mucous membrane of the upper part of this surface and is known as the *pharyngeal tonsil*.

The pharyngeal tonsil is visible to the naked eye during the later months of foetal life and usually increases in size up to the age of six or seven years, after which it not infrequently begins to atrophy. In a child of eighteen months it forms a forwardly projecting pyramidal prominence the apex of which is near the nasal septum, and the base at the junction of the roof and posterior wall of the nasal part of the pharynx. The prominence consists of a number of folds which radiate forwards and laterally from a median recess, termed the *pharyngeal bursa*, which runs upwards and backwards for some distance into its substance. The folds consist mainly of diffuse lymphoid tissue, but there are also some deeply placed mucous glands. The pharyngeal bursa lies close to the base of the pharyngeal tonsil and presents the appearance of a blind recess. In the embryo, the notochord lies for a short distance below the base of the skull, in the region of the developing basilar part of the occipital bone (fig. 116, p. 107); here it is attached to the endoderm forming the roof of the primitive pharynx, and with subsequent growth of this region, the notochordal attachment draws out an angled recess of the endoderm (the pouch of Luschka) which forms the pharyngeal bursa. The lateral prolongation of the pharyngeal tonsil behind the pharyngeal opening of the auditory tube is known as the *tubal tonsil*.

The **oral part of the pharynx** reaches from the soft palate to the upper border of the epiglottis. It opens anteriorly, through the oropharyngeal isthmus, into the mouth and faces the pharyngeal part of the tongue. Its lateral wall presents the palatopharyngeal arch and the tonsil. Posteriorly, it is supported by the body of the second cervical vertebra and the upper part of the body of the third.

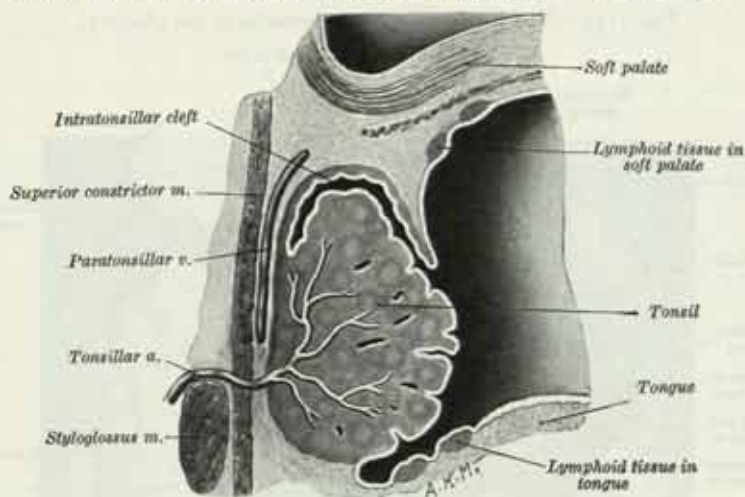
The *palatopharyngeal arch* lies behind and projects farther towards the median plane than the palatoglossal arch; it runs downwards, laterally and backwards from the margin of the uvula to the side of the pharynx, and is formed by the projection of the Palatopharyngeus (p. 1348), covered with mucous membrane. On each side the palatopharyngeal and palatoglossal arches are separated by a triangular recess, the *tonsillar sinus*, in which the tonsil is lodged.

The **palatine tonsils** (fig. 1145) are two masses of lymphoid tissue, situated in

* F. Wood Jones (*J. Anat.*, 74, 1940), from a study of the comparative anatomy of the soft palate, believes that the 'nasal part of the pharynx' in man is really a part of the nasal cavities, and that the soft palate really separates the pharynx from the nasal chambers.

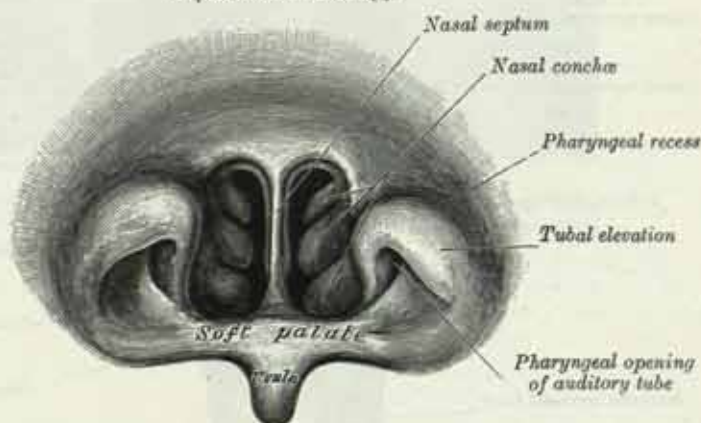
the lateral walls of the oral part of the pharynx. Each tonsil is placed in the triangular recess (*tonsillar sinus*) between the diverging palatoglossal and palatopharyngeal arches. Its medial surface is free and forms a conspicuous projection

FIG. 1152.—A coronal section through the tonsil *in situ*. Diagrammatic.



into the pharynx during childhood, but the size of this projection is not a true indication of the size of the organ. Its deep, or lateral, aspect extends upwards, downwards and forwards beyond the limits of the medial surface and is imbedded below the level of the mucous membrane. Inferiorly, it extends into the dorsum of the tongue; superiorly, it invades the soft palate; and, anteriorly, it may extend for some distance imbedded beneath the palatoglossal arch. The tonsil is variable in

FIG. 1153.—The front of the nasal part of the pharynx, as seen in posterior rhinoscopy.

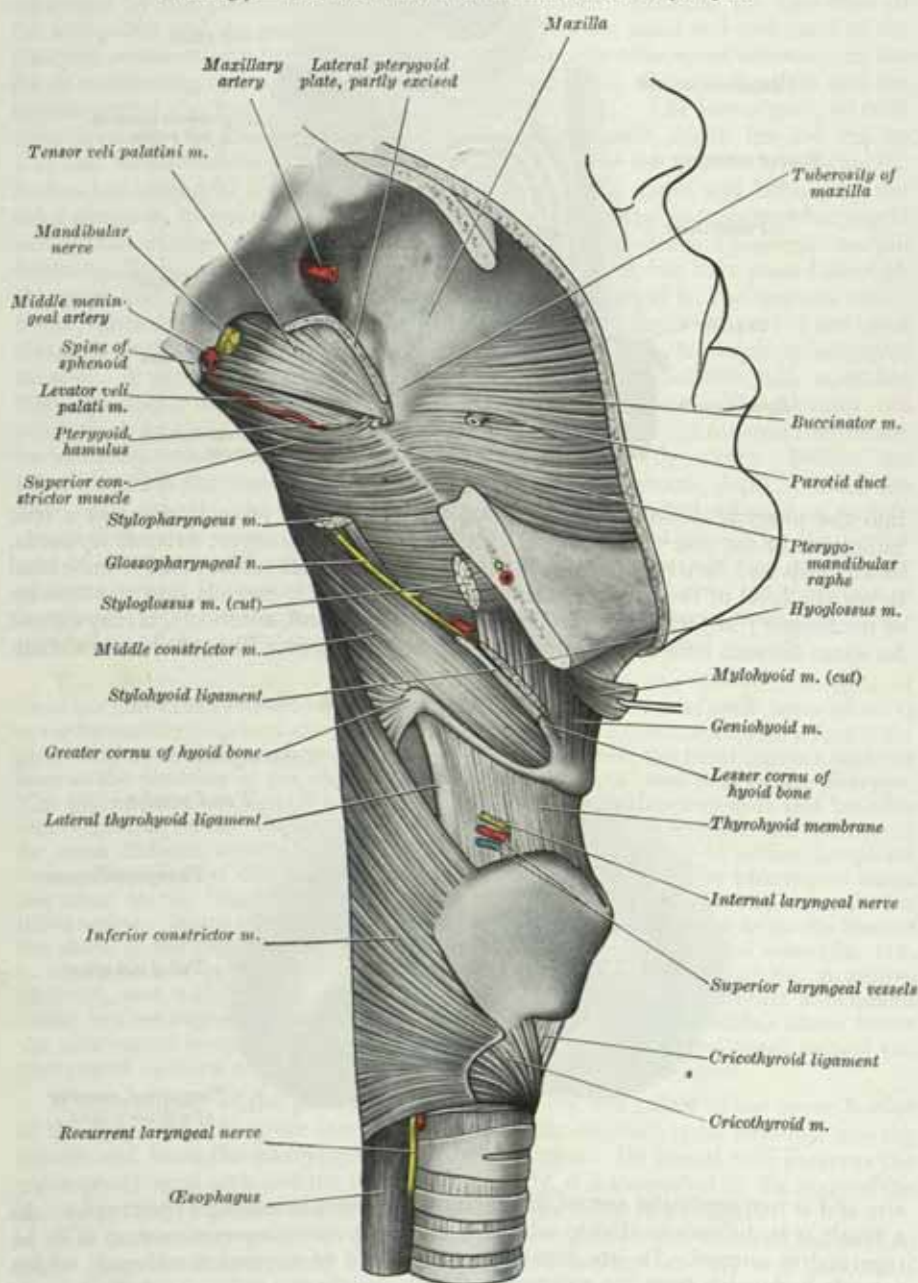


size and is frequently the seat of inflammatory changes involving hypertrophy. As a result it is difficult to decide which of the many varieties encountered is to be regarded as normal. In late foetal life, a free fold of mucous membrane, which extends backwards from the palatoglossal arch, covers the anterior-inferior part of the tonsil and is termed the *plica triangularis*. In the child this fold is usually invaded by lymphoid tissue and becomes incorporated in the tonsil; it is only rarely present as a small, free fold which extends backwards from the lower part of the palatoglossal arch.

The upper part of the tonsil contains a deep *intratonsillar cleft*, frequently and erroneously termed the *supratonsillar fossa*. This cleft does not lie above the tonsil, but actually in its substance, and its upper wall contains a quantity of lymphoid

tissue (fig. 1152) which may reach a large size and extend into the soft palate. The mouth of the cleft is semilunar in shape and is parallel to the curve of the dorsum of the tongue. After puberty the imbedded part of the tonsil diminishes considerably in size and the projecting medial surface becomes flattened and much less prominent.

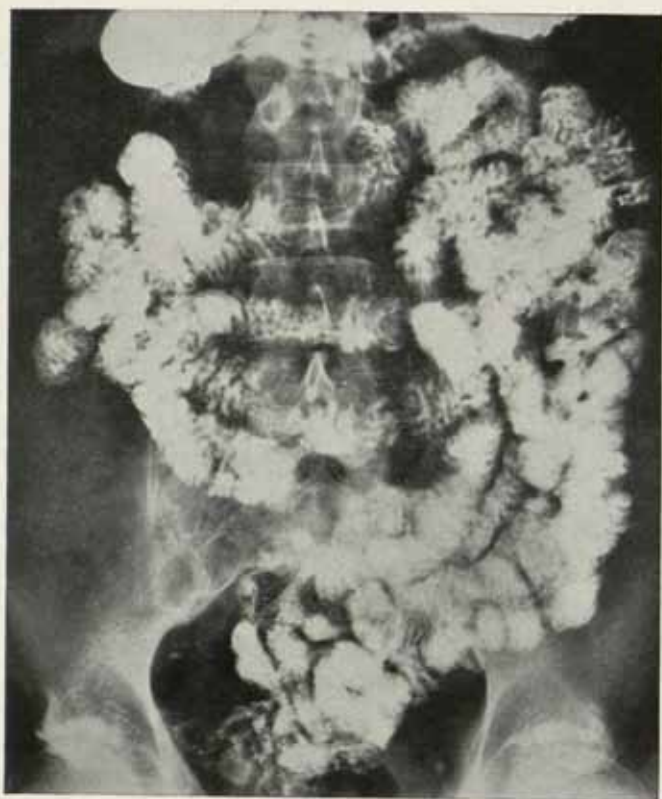
FIG. 1154.—The Buccinator and the muscles of the pharynx.



The *free surface* of the tonsil presents from twelve to fifteen orifices leading into deep, narrow recesses, termed the *tonsillar crypts*, which penetrate nearly the whole thickness of the tonsil and from which numerous follicles branch out into the tonsillar substance.

The *lateral or deep surface* is covered by a layer of fibrous tissue, termed the *capsule*. In most of its extent the tonsil and its capsule can easily be separated from

PLATE XXVII



Radiograph of the small intestine after a barium meal. The 'feathery' appearance is due to the presence of the circular folds in the mucous coat.

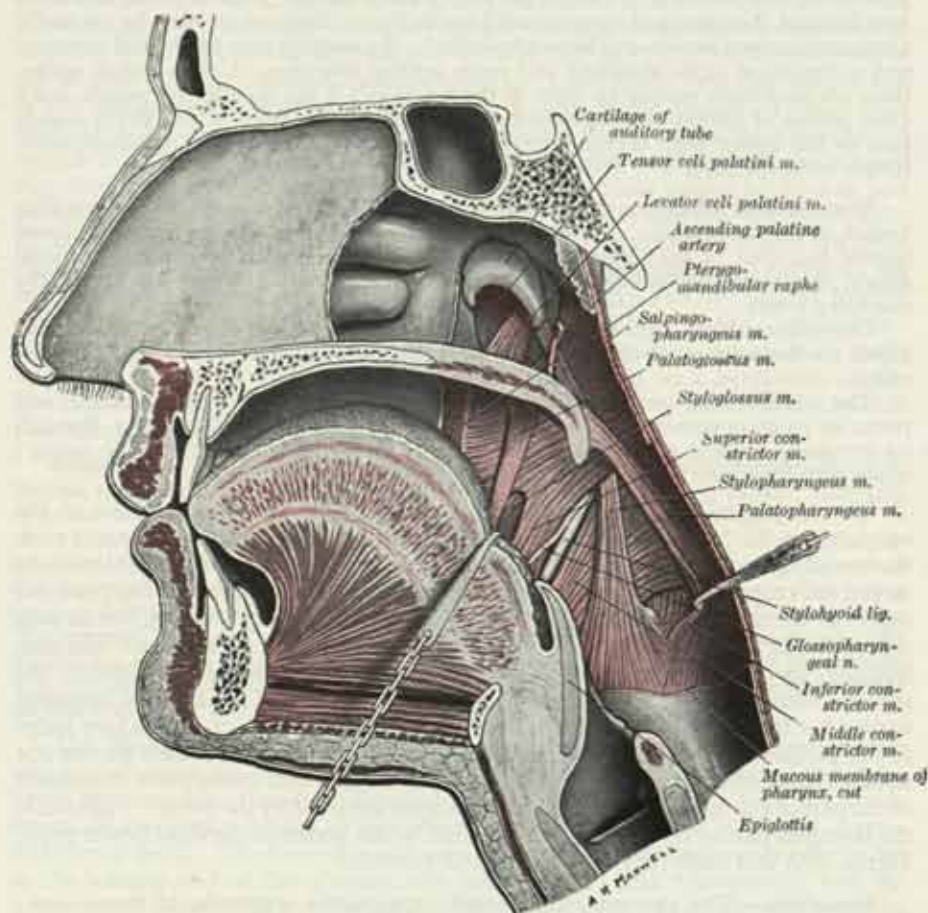
PLATE XXVIII



Radiograph of the large intestine after a barium enema. 1= right colic flexure; 2= left colic flexure. The arrow points to the sigmoid colon. Note the sacculations (hastrations) of the gut, and the different levels of the two flexures.

the muscular wall of the pharynx, which is formed in this situation by the Superior constrictor muscle with the Styloglossus on its lateral side (fig. 1155). At its antero-inferior part the capsule is firmly connected to the side of the tongue, and behind this point it receives the insertion of some muscular fibres of the Palatoglossus and Palatopharyngeus. In the latter situation the tonsillar artery, which is a branch of the facial artery, pierces the Superior constrictor muscle and at once enters the tonsil, accompanied by two venæ comitantes. An important, and sometimes large, palatine vein (the external palatine or 'paratonsillar vein') descends from the soft palate across the lateral aspect of the capsule of the tonsil before piercing the pharyngeal wall (fig. 1152). It is this vessel which is responsible for the excessive

FIG. 1155.—Median sagittal section of the head, showing a dissection of the interior of the pharynx, after the removal of the mucous membrane.



In order that the structures might be displayed satisfactorily, the bodies of the cervical vertebrae were removed and the cut posterior wall of the pharynx was then drawn backwards and laterally. The Palatopharyngeus is drawn backwards to show the upper fibres of the Inferior constrictor, and the dorsum of the tongue is drawn forwards to display a part of the Styloglossus in the angular interval between the mandibular and the lingual fibres of origin of the Superior constrictor.

venous hæmorrhage from the upper angle of the tonsillar sinus sometimes encountered in excision of the tonsil.* The muscular wall of the tonsillar sinus separates the tonsil from the ascending palatine artery and, occasionally, from the facial artery itself (p. 742), which, if very tortuous, may be very closely related to the pharyngeal wall opposite the lower part of the tonsil. The internal carotid artery lies 2.5 cm. behind and lateral to the tonsil.

The tonsils form part of a circular band of lymphoid tissue which guards the opening into the digestive and respiratory tubes. The anterior and lower part of the ring is formed by the lingual tonsil; the lateral portions consist of the tonsils and

* D. Browne, *J. Anat.*, 63, 1928.

the lymphoid collections in the vicinity of the auditory tubes; the ring is completed behind and above by the pharyngeal tonsil (p. 1382). Smaller collections of lymphoid tissue are found in the intervals between these main masses.

Surface Anatomy.—The tonsil lies behind the third lower molar tooth and is represented by an oval area over the lower part of the masseter muscle, a little above and in front of the angle of the mandible.

Structure.—The crypts of the tonsil are lined by stratified squamous epithelium, which is continuous with that of the mucous membrane of the pharynx, and is invaded by numerous lymphocytes; some of the latter pass into the mouth and form the so-called salivary corpuscles. The tonsil consists of lymphoid tissue which is arranged in nodules or follicles. The lymphocytes are less closely packed in the centre of each nodule, which is described as a *germ-centre*, because multiplication of the lymphocytes goes on in this situation. The crypts may contain cheesy plugs of living and dead lymphocytes, bacteria and desquamated epithelium; these plugs may be gradually eliminated or may remain and become calcified; the bacteria may cause local infection and suppuration or be absorbed and cause general infection. Unlike lymph nodes, there are no lymph sinuses (p. 880) in the tonsil and it has no afferent vessels, but a close plexus of lymph vessels surrounds each follicle and from it the lymph vessels pass to the upper deep cervical lymph nodes, and especially to the jugulodigastric lymph node (p. 885).

Vessels and Nerves.—The chief artery supplying the tonsil is the tonsillar branch of the facial artery. In addition, it may receive a few twigs from the dorsal lingual branches of the lingual artery, the ascending palatine branch of the facial artery, the ascending pharyngeal artery, and the greater palatine branch of the maxillary artery.

One or more veins leave the lower part of the deep aspect of the tonsil and at once pierce the Superior constrictor muscle to join the 'paratonsillar', pharyngeal or facial veins.

The nerves are derived from the pterygopalatine ganglion, through the middle and posterior palatine nerves, and from the glossopharyngeal nerve. The latter, through its tympanic branch, also supplies the mucous membrane of the tympanic cavity; hence tonsillitis may be accompanied by pain referred to the ear.

The laryngeal part of the pharynx reaches from the upper border of the epiglottis to the lower border of the cricoid cartilage, where it is continuous with the œsophagus. Its anterior wall presents, from above downwards, the inlet of the larynx (p. 1309), the posterior surfaces of the arytenoid cartilages and the posterior aspect of the cricoid cartilage. A small recess, termed the *piriform fossa*, lies on each side of the laryngeal orifice; it is bounded, medially, by the aryepiglottic fold and, laterally, by the thyroid cartilage and the thyrohyoid membrane. Beneath the mucous membrane of the piriform fossa lie the branches of the internal laryngeal nerve after they have pierced the thyrohyoid membrane; foreign bodies may lodge in the piriform fossa and, if the instrument employed to remove them pierces the mucous membrane, the nerve is liable to be damaged, with consequent anaesthesia of the part of the mucous membrane of the larynx supplied by the nerve. Posteriorly the laryngeal part of the pharynx is supported by the bodies of the third (lower part), fourth, fifth and sixth (upper part) cervical vertebrae.

Structure.—The pharynx is composed, from within outwards, of three coats: mucous, fibrous and muscular, the last being covered by the thin buccopharyngeal fascia, which covers the outer surface of the Constrictor muscles and extends forwards over the pterygomandibular raphe on to the Buccinator muscle.

The mucous coat is continuous with that of the auditory tubes, nasal cavity, mouth and larynx. In the nasal part of the pharynx its epithelium is columnar and ciliated; in the oral and laryngeal portions it is stratified squamous. Between the region covered by ciliated columnar epithelium and that covered by squamous epithelium, there is a narrow intermediate zone where the epithelium is cubical, and the cilia are imperfect or absent. Superiorly, this zone lies near the nasal septum; laterally it passes over the orifice of the auditory tube and inclines backwards at the union of the soft palate with the lateral wall (see also pp. 1346, 1389). Racemose mucous glands are found beneath the mucous membrane, and are especially numerous at the upper part of the pharynx around the orifices of the auditory tubes.

The fibrous coat is situated between the mucous and muscular layers. It is thick above (pharyngobasilar fascia) where the muscular fibres are wanting, and is firmly connected to the basilar portion of the occipital bone and to the petrous part of the temporal bone medial to the carotid canal, bridging under the auditory tube and

extending forwards to be attached to the posterior border of the medial pterygoid plate and to the pterygomandibular raphe. As it descends it diminishes in thickness, and is gradually lost. It is strengthened posteriorly by a strong fibrous band, which is attached above to the pharyngeal tubercle on the under surface of the basilar portion of the occipital bone, and passes downwards as a median raphe (the *pharyngeal raphe*) which gives attachment to the Constrictor muscles.

The *muscular coat* consists of the muscles of the pharynx.

The **muscles of the pharynx** (figs. 1149, 1154-1156) are :

Constrictor pharyngis inferior.	Stylopharyngeus.
Constrictor pharyngis medius.	Salpingopharyngeus.
Constrictor pharyngis superior.	Palatopharyngeus.*

The **Inferior constrictor muscle of the pharynx** is the thickest of the constrictors and consists of two parts, the Cricopharyngeus and the Thyropharyngeus. It arises (fig. 1087) from the side of the cricoid cartilage in the interval between the origin of the Cricothyroid in front, and the articular facet for the inferior horn of the thyroid cartilage behind (*Cricopharyngeus*). It also arises from the oblique line of the lamina of the thyroid cartilage, from a strip of the surface of the lamina behind this line, from a fine tendinous band, which is thrown across the Cricothyroid muscle from the inferior thyroid tubercle to the cricoid cartilage, and, by a small slip, from the inferior horn (*Thyropharyngeus*). The fibres spread backwards and medially, and are inserted with the muscle of the opposite side into a fibrous raphe in the posterior median line of the pharynx. The inferior fibres, which are horizontal, are continuous with the circular fibres of the œsophagus and surround the narrowest part of the pharynx; the rest ascend obliquely, and overlap the Middle constrictor. During swallowing, the Cricopharyngeus acts as the 'sphincteric' part of the muscle, while the Thyropharyngeus acts as the 'propulsive' part; failure of relaxation of the Cricopharyngeus may result in a herniation of the pharyngeal mucous membrane posteriorly between the two parts of the muscle (miscalled 'pressure-diverticulum of the œsophagus').

Relations.—The Inferior constrictor is covered with the buccopharyngeal fascia. *Behind*, the muscle is in relation with the prevertebral fascia and muscles; *laterally*, with the thyroid gland, the common carotid artery, and the Sternothyroid; by its *internal surface*, with the Middle constrictor, the Stylopharyngeus, the Palatopharyngeus and the fibrous coat. The internal laryngeal nerve and the laryngeal branch of the superior thyroid artery run to the thyrohyoid membrane between the upper border of the Inferior constrictor and the lower border of the Middle constrictor. The external laryngeal nerve runs down on the superficial surface of the muscle, just behind the origin from the thyroid cartilage, and pierces the lower part of the muscle. The recurrent laryngeal nerve and the laryngeal branch of the inferior thyroid artery ascend deep to its lower border, before they enter the larynx.

The **Middle constrictor muscle of the pharynx** is a fan-shaped muscle which arises from the lesser horn of the hyoid bone and the lower part of the stylohyoid ligament (the chondropharyngeal part of the muscle), and from the whole length of the upper border of the greater horn of the hyoid bone (the ceratopharyngeal part). The lower fibres descend deep to the Inferior constrictor, as far as the inferior end of the pharynx, the middle fibres pass transversely, and the upper fibres ascend and overlap the Superior constrictor. It is inserted, with the muscle of the opposite side, into the posterior median fibrous raphe.

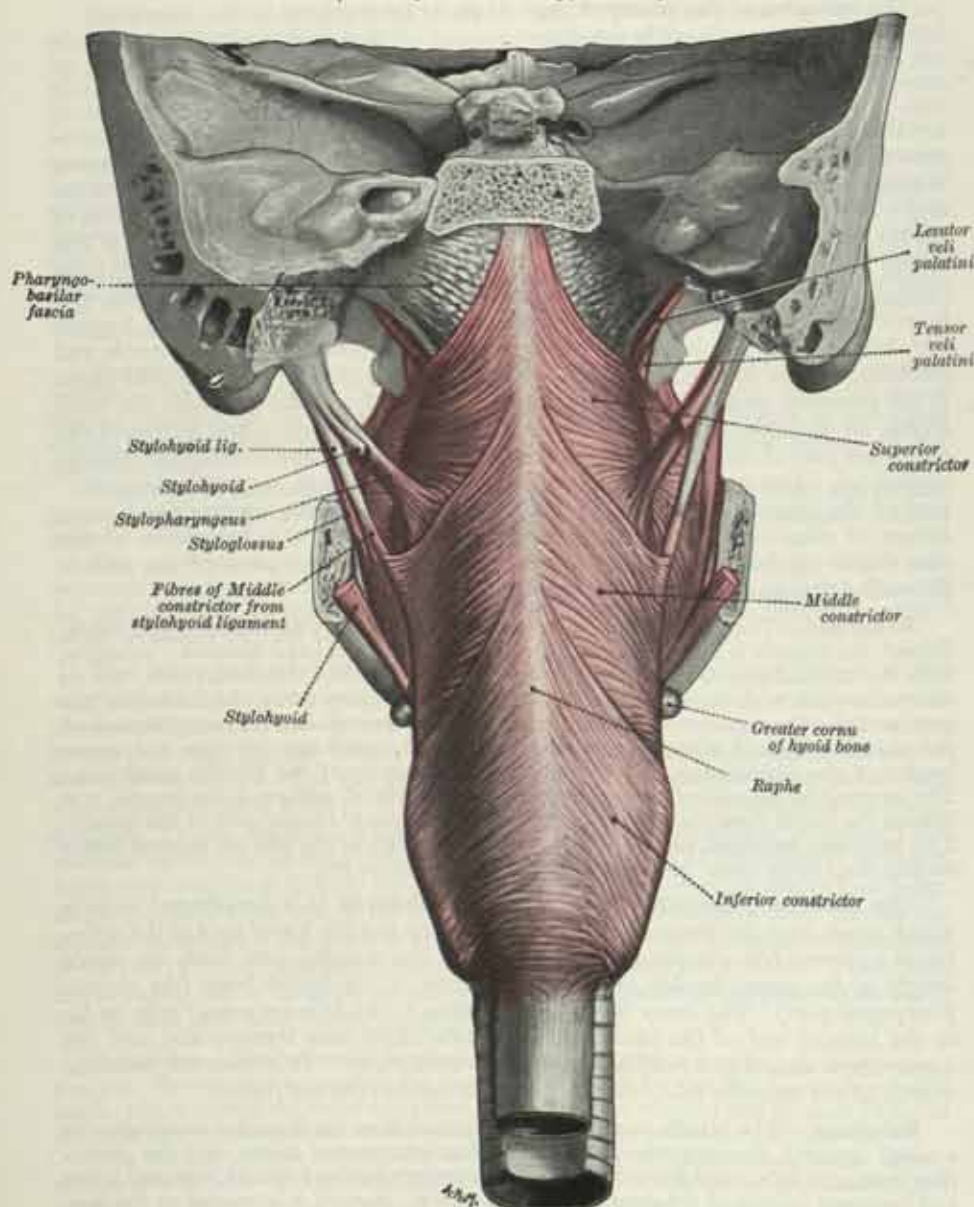
Relations.—The Middle constrictor is separated from the Superior constrictor by a small interval, through which pass the glossopharyngeal nerve and the Stylopharyngeus muscle; and from the Inferior constrictor by the internal laryngeal nerve and laryngeal branch of the superior thyroid artery. *Behind*, it is related to the prevertebral fascia, the Longus cervicis and the Longus capitis. *Laterally*, it is in relation with the carotid vessels, the pharyngeal plexus of nerves and some lymph nodes. Near its origin it is covered with the Hyoglossus, from which it is separated by the lingual artery. Its *internal surface* lies upon the Superior constrictor, the Stylopharyngeus, the Palatopharyngeus and the fibrous coat.

The **Superior constrictor muscle of the pharynx** is a quadrilateral muscle, thinner and paler than the other two. It arises from the pterygoid hamulus, and sometimes from the adjoining part of the posterior margin of the medial pterygoid plate, from the pterygomandibular raphe, from the posterior end of the mylohyoid

* The Palatopharyngeus is described with the muscles of the palate (p. 1348).

line on the inner surface of the mandible, and by a few fibres from the side of the tongue (fig. 1155). According to the different parts of the origin of the muscle (as above), the Superior constrictor consists of the following parts: pterygo-pharyngeal, buccopharyngeal, mylopharyngeal and glossopharyngeal. The fibres

FIG. 1156.—The muscles of the pharynx; posterior view.
(From Quain's *Anatomy*, XI. Ed.)



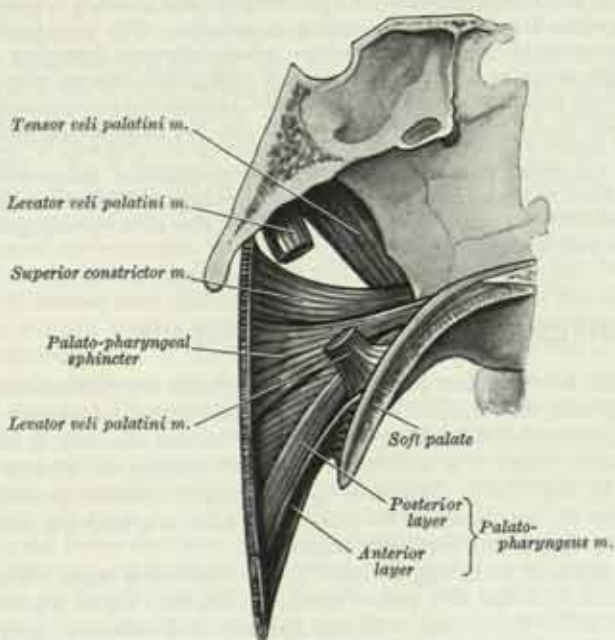
curve backwards to be inserted into the median raphe, being also prolonged by means of an aponeurosis to the pharyngeal tubercle on the basilar part of the occipital bone. The superior fibres arch beneath the Levator veli palatini and the auditory tube. An interval exists between the upper border of the muscle and the base of the skull to give passage to the auditory tube. It is bounded in front by the medial pterygoid plate and is closed by the pharyngobasilar fascia (p. 1386).

A constant band of muscle fibres arises from the anterior and lateral part of the upper surface of the palatine aponeurosis and sweeps backwards, lateral to the Levator veli palatini, to blend with the inner surface of the Superior constrictor

muscle near its upper border (fig. 1157). Whillis * has termed this band the *Palatopharyngeal sphincter* and has pointed out that it produces a rounded ridge on the pharyngeal wall (known as the 'ridge of Passavant'), which can be seen when the soft palate is elevated in the living. These fibres are much hypertrophied in cases of complete cleft palate. The change from the columnar, ciliated, 'respiratory' epithelium to the stratified squamous epithelium on the upper surface of the soft palate takes place where the Palatopharyngeal sphincter is attached to the palate (p. 1346).

Relations.—The Superior constrictor muscle is in relation by its *external surface* with the prevertebral fascia and muscles, the ascending pharyngeal artery and pharyngeal venous plexus, the glossopharyngeal and lingual nerves, the Styloglossus, Middle Constrictor and Medial pterygoid, the stylohyoid ligament and the Stylopharyngeus. The internal carotid artery, the sympathetic trunk, the hypoglossal nerve, the internal jugular vein and the styloid process are more distant relations. By its *internal surface* it is in relation with the Palatopharyngeus, the capsule of the tonsil, and the pharyngobasilar fascia. Its *upper border* is separated from the base

FIG. 1157.—A dissection to show the muscles of the left half of the soft palate and the adjoining part of the wall of the pharynx. (After Whillis.)



of the skull by a crescentic interval in which the Levator veli palatini, the Tensor veli palatini and the auditory tube are situated. Its lower border is separated from the Middle constrictor by the Stylopharyngeus and glossopharyngeal nerve. *In front* it is separated from the Buccinator by the pterygomandibular raphe.

Nerve-supply.—The Constrictors of the pharynx are supplied by the pharyngeal plexus (p. 1129). In addition the Inferior constrictor receives branches from the external and recurrent laryngeal nerves.

Actions.—The actions of the constrictor muscles are described on p. 1391.

The **Stylopharyngeus** (figs. 1149, 1155) is a long, slender muscle which is cylindrical above and flattened below. It arises from the medial side of the base of the styloid process of the temporal bone, descends along the side of the pharynx, passes between the Superior and the Middle constrictors, and spreads out beneath the mucous membrane. Some of its fibres are lost in the constrictor muscles and in the lateral glosso-epiglottic fold, while others are inserted with the Palatopharyngeus into the posterior border of the thyroid cartilage. The glossopharyngeal nerve winds round the posterior border and the lateral side of the Stylopharyngeus muscle

and passes through the interval between the Superior and the Middle constrictors to reach the tongue.

Nerve-supply.—The Stylopharyngeus is supplied by a branch from the glossopharyngeal nerve.

Action.—*See below, 'The Mechanism of Deglutition.'*

The **Salpingopharyngeus** (fig. 1114) arises from the inferior part of the cartilage of the auditory tube near its pharyngeal opening; it passes downwards and blends with the Palatopharyngeus.

Nerve-supply.—The Salpingopharyngeus is supplied by the pharyngeal plexus.

Action.—The Salpingopharyngeus raises the upper part of the lateral wall of the pharynx, i.e. the part above the attachment of the Stylopharyngeus.

Vessels and Nerves.—The *arteries* supplying the pharynx are derived from the ascending pharyngeal, the ascending palatine and tonsillar branches of the facial artery, branches of the maxillary artery (greater palatine, pharyngeal and the artery of the pterygoid canal) and the dorsal lingual branches of the lingual artery. The *veins* form a plexus which communicates above with the pterygoid plexus and drains into the internal jugular and facial veins.

The *lymph vessels* are described on pp. 888 and 891.

The *nerve-supply* is derived chiefly from the pharyngeal plexus which is formed by branches from the glossopharyngeal, vagus and sympathetic. The principal *motor* element is the cranial part of the accessory nerve, which, through branches of the vagus, supplies all the muscles of the pharynx and soft palate, except the Stylopharyngeus (supplied by the glossopharyngeal) and the Tensor veli palatini (supplied by the mandibular nerve). The main *sensory* nerves are the glossopharyngeal and vagus; much of the mucous membrane of the nasal part of the pharynx is supplied by branches of the maxillary nerve (through the pterygopalatine ganglion); the mucous membrane of the soft palate is supplied by the middle and posterior palatine and glossopharyngeal nerves; the tonsil is supplied by the glossopharyngeal and middle and posterior palatine nerves.

MOVEMENTS OF THE SOFT PALATE

The movements of the soft palate play an important part in deglutition, in speech and in the act of blowing, and involve a greater or lesser degree of closure of the pharyngeal isthmus, necessitated by these acts. The closure is maximal in blowing out through the mouth, when it is essential to prevent entirely the escape of air through the nose. In deglutition closure of the pharyngeal isthmus prevents the food from passing into the nasal part of the pharynx, whilst in speech the closure is maximal in the production of the explosive consonants.

Closure of the isthmus is brought about in the following way. The two Levatores veli palatini pull the soft palate upwards and backwards towards the posterior pharyngeal wall. Coincident with this movement the fibres of the Palatopharyngeal sphincter raise a rounded ridge on the posterior pharyngeal wall, which meets the nasal surface of the soft palate over a considerable area, and it is at the upper limit of this area of contact that the mucous membrane on the upper surface of the palate changes from the respiratory to the pharyngeal type.

The Tensor veli palatini is active in deglutition rather than in speech, and by producing a localised depression of the anterior part of the palate (p. 1348) squeezes the bolus against the tongue and so helps to project it through the oral pharynx.

THE MECHANISM OF DEGLUTITION

The first stage of the act of swallowing, or deglutition, is voluntary in character. The anterior part of the tongue is raised and pressed against the hard palate, the movement commencing at the tip of the tongue and spreading backwards rapidly. By this mechanism a bolus placed on the tongue behind the tip passes backwards to the posterior part of the mouth. At the end of the first stage, the soft palate closes down on to the back of the tongue to help to form the bolus. The movements of the tongue are effected by the intrinsic muscles, especially the Superior longitudinal and Transverse. At the same time the hyoid bone moves forwards and upwards a little and becomes fixed owing to contraction of the Geniohyoid, Mylohyoid,

Digastric and Stylohyoid muscles. By elevation of the posterior part of the tongue, which is drawn upwards and backwards by the Styloglossi, and by the approximation of the palatoglossal arches, caused by the contraction of the Palatoglossi, the bolus is now passed through the oropharyngeal isthmus into the oral part of the pharynx and the second, or involuntary, stage of the act of swallowing begins. In swallowing fluids, the intrinsic tongue muscles are used to squirt the fluid back through the mouth; this is succeeded by contraction of the Mylohyoid which bulges the base of the tongue into the oral pharynx. In swallowing solids, only the latter action is used, except when the mouth is being cleansed of saliva and debris after the bolus has been swallowed.*

In the second stage, the soft palate is elevated (by the Levator muscles) and tightened (by the Tensor muscles). In addition it is closely and firmly approximated to the posterior pharyngeal wall by the contraction of the Palatopharyngeal sphincter (p. 1389) and the upper fibres of the Superior constrictor muscle. The pharyngeal isthmus is tightly closed and the bolus is prevented from passing upwards. At the same time the larynx is drawn upwards behind the hyoid bone and the pharynx ascends with it. This upward displacement is brought about by the Stylopharyngeus, Salpingopharyngeus, Thyrohyoid and Palatopharyngeus muscles. Simultaneously the aryepiglottic folds are approximated and the arytenoid cartilages are drawn upwards and forwards by the contraction of the Aryepiglottic, Oblique arytenoid and Thyroarytenoid muscles. Provision is thus made to prevent the bolus from entering the larynx. Partly under the influence of gravity—when the body is in the erect or sitting posture—and partly urged onwards by the successive contractions of the Superior and Middle constrictor muscles, the bolus slips over the posterior aspect of the epiglottis, the closed inlet of the larynx and the posterior surfaces of the arytenoid cartilages to gain the lowest part of the pharynx. During this stage its passage is facilitated by the action of the Palatopharyngei, which shorten the pharynx and pull it upwards. These two muscles, when contracting, convert the surface of the posterior pharyngeal wall into an inclined plane directed downward and backwards and on its under surface the bolus descends. The aryepiglottic folds provide lateral food channels leading from the sides of the epiglottis through the piriform fossæ to the œsophagus. They are kept more or less tense and upright by the backward pull of the Posterior cricoarytenoids on the arytenoid cartilages (to which the folds are attached) and by the muscles in the folds themselves (Aryepiglottics and Thyroepiglottics), assisted by the cuneiform cartilages, which act as passive props. In paralysis of these muscles (which are supplied by the recurrent laryngeal nerves), the inlet of the larynx is not closed during swallowing, the aryepiglottic folds fall medially, and fluids tend to overflow into the larynx.

The last stage in the act is effected by the Inferior constrictor muscle, which passes the bolus onwards into the œsophagus (*see* p. 1387).

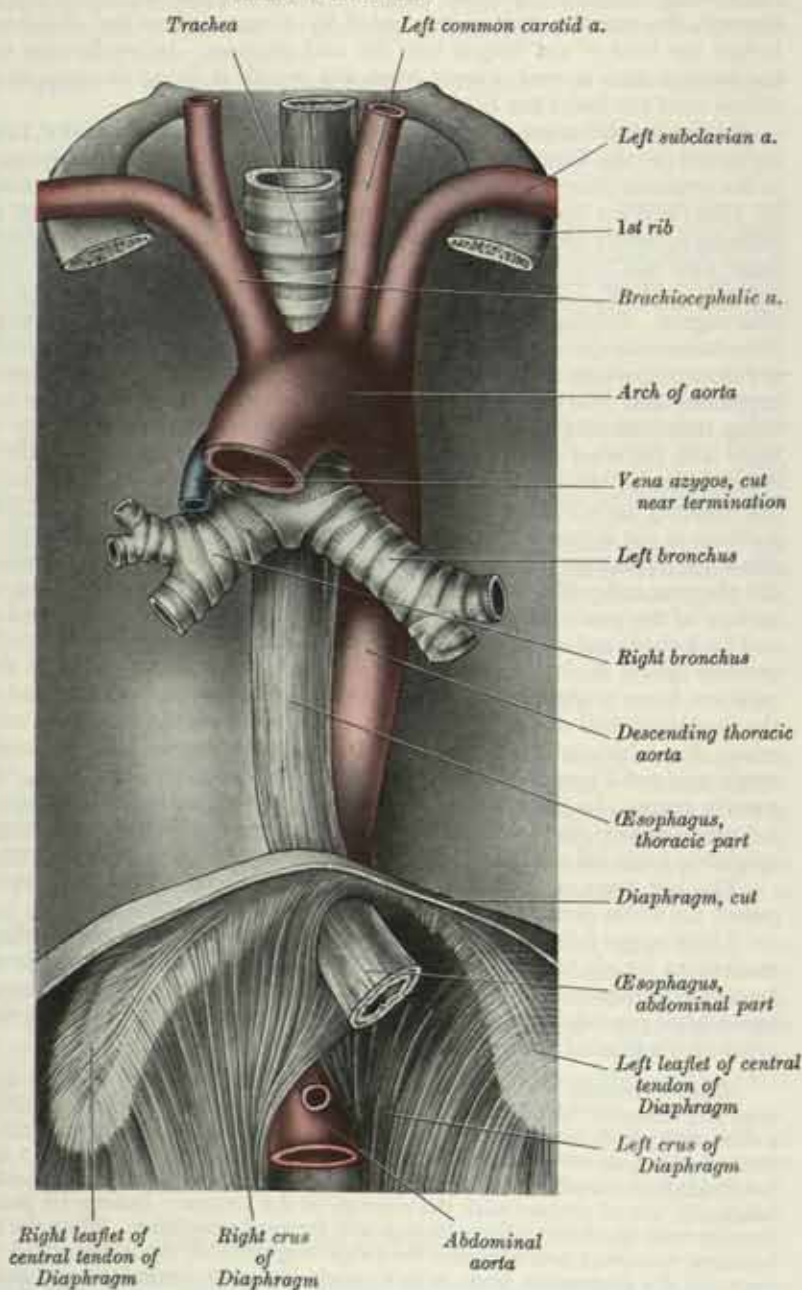
These stages follow one another in rapid succession, but it is not difficult for the student to satisfy himself, by palpation of the body of the hyoid bone and the laryngeal prominence during the act, that elevation and forward movement of the hyoid bone precede elevation of the larynx and that the amount of upward movement of the thyroid cartilage is considerable.

Applied Anatomy.—In young children overgrowth of the lymphoid tissue in the nose and nasopharynx (adenoids), with or without enlargement of the tonsils, produces a characteristic deformity of the face, the 'adenoid facies', by obstructing respiration through the nose and making mouth-breathing more or less obligatory. As the child has to keep its mouth open in order to breathe, the bony palate and alveolar arch are habitually out of contact with the dorsum of the tongue; lacking its pressure, they develop with an abnormally high arch and forward projection. Thus the hard palate becomes narrowed laterally, and the projecting alveolar processes afford insufficient room for the permanent teeth, which appear crowded, irregularly set, and overhang those in the lower jaw. The facial surfaces of the maxillæ become pinched together, with narrowing of the nasal cavities and maxillary air-sinuses. The nose itself shows abnormality in shape of two chief types: (1) The bridge remaining normal, the apex looks thin and pinched because the alæ fall inwards from disuse of the dilator muscles, and the nares become elongated, narrow, and barely capable of voluntary dilatation; there is often a depression in the region of the lower nasal cartilage. (2) Less commonly the bones forming the bridge of the nose are pressed apart by the underlying adenoid growths, making it appear thicker and broader than normal; the dilators of the nares

* J. Whillis, *J. Anat. Lond.*, 80, 1946, 115-116.

atrophy from disuse, and the nares look unduly small and rounded. In all cases of adenoids the upper lip is drawn up, still further exposing the projecting front upper teeth. The face is lengthened by dropping of the lower jaw ; the whole expression of

FIG. 1158.—A dissection to expose the œsophagus in the posterior mediastinum and in the abdomen.



the child is highly characteristic, suggesting vacuity and inattention, the latter being due to the deafness so often associated with nasal obstruction and caused by blocking of the pharyngeal openings of the auditory tubes.

THE ŒSOPHAGUS (fig. 1158) (Pl. XX)

The **œsophagus**, or **gullet**, is a muscular canal, from 23 cm. to 25 cm. (10 inches) long, extending from the pharynx to the stomach. It begins in the neck at

the lower border of the cricoid cartilage, opposite the sixth cervical vertebra, where it is continuous with the lower end of the pharynx. It descends along the front of the vertebral column, through the superior and posterior parts of the mediastinum, pierces the Diaphragm opposite the tenth thoracic vertebra, and ends at the cardiac orifice of the stomach at the level of the eleventh thoracic vertebra. The general direction of the œsophagus is vertical; but it presents two slight curves in its course. At its commencement it is placed in the median plane; but it inclines slightly to the left side as far as the root of the neck, gradually passes again to the median plane, which it reaches at the level of the fifth thoracic vertebra, and again, at the level of the seventh thoracic vertebra, deviates to the left and then passes forwards to the œsophageal opening in the Diaphragm. The œsophagus also presents anteroposterior flexures corresponding to the curvatures of the cervical and thoracic portions of the vertebral column. It is the narrowest part of the digestive tube (exclusive of the vermiform appendix), and is constricted (*a*) at its commencement, 6 inches from the incisor teeth, (*b*) where it is crossed by the aortic arch, 9 inches from the incisor teeth, (*c*) where it is crossed by the left bronchus, 11 inches from the incisors, and (*d*) where it pierces the Diaphragm, 15 to 16 inches from the incisors. The sites of these constrictions are important clinically in connexion with the passage of instruments along the œsophagus.

Relations.—The **cervical part** of the œsophagus has the following relations. *In front*, lies the trachea, to the posterior membranous wall of which it is attached by loose connective tissue; the recurrent laryngeal nerves ascend, one on each side, in, or slightly in front of, the groove between the trachea and œsophagus. *Behind*, it lies on the vertebral column, the Longus cervicis muscle and the pre-vertebral layer of the deep cervical fascia. *Laterally*, on each side, lie the corresponding common carotid artery and the posterior part of the lateral lobe of the thyroid gland; in the lower part of the neck, where the œsophagus projects to the left side, it has a closer relation to the carotid sheath and the thyroid gland than on the right side. The thoracic duct ascends for a short distance along the left edge of the œsophagus.

The **thoracic part** of the œsophagus (figs. 1092, 1094–1097, 1102, 1158) is at first situated in the superior mediastinum between the trachea and the vertebral column, a little to the left of the median plane. It passes behind and to the right of the aortic arch and descends in the posterior mediastinum along the right side of the descending thoracic aorta. Below, as it inclines to the left, it crosses in front of the aorta, and enters the abdomen through the Diaphragm at the level of the tenth thoracic vertebra. It is in relation, *in front*, (from above downwards), with the trachea, the right pulmonary artery, the left bronchus, the pericardium (separating it from the left atrium), and the Diaphragm; *behind*, it rests upon the vertebral column, the Longus cervicis muscles, the right posterior (aortic) intercostal arteries, the thoracic duct, the azygos vein and the terminal parts of the hemiazygos veins; and below, near the Diaphragm, upon the front of the aorta. In the posterior mediastinum an elongated recess of the right pleural sac intervenes between the œsophagus and the vena azygos and vertebral column. On its *left* side, in the superior mediastinum the terminal part of the aortic arch, the left subclavian artery, the thoracic duct, and left pleura are immediate relations, while the left recurrent laryngeal nerve runs upwards in the groove between it and the trachea; in the posterior mediastinum it is in relation with the descending thoracic aorta and the left pleura. On its *right* side it is related to the right pleura, the azygos vein intervening as it arches forwards above the right bronchus to join the superior vena cava. Below the roots of the lungs the vagus nerves descend in close contact with it, the right nerve chiefly behind, and the left chiefly in front of it; the two nerves unite to form a plexus around the tube (p. 1132).

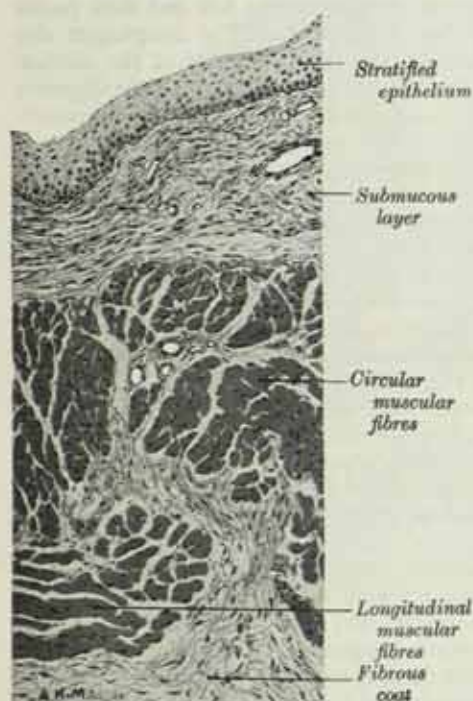
In the lower part of the posterior mediastinum the thoracic duct lies behind and to the right of the œsophagus; higher up, it is placed behind it, and crossing to the left about the level of the fifth thoracic vertebra, is continued upwards on its left side.

On the right side of the œsophagus, just above the Diaphragm, a small serous sac (the *infra-cardiac bursa*) is sometimes found; it represents the upper detached part of the right pneumato-enteric recess (p. 196).

The **abdominal part** of the œsophagus, having passed through the right crus of the Diaphragm (p. 586) slightly to the left of the median plane at the level of the

tenth thoracic vertebra, lies in the œsophageal groove on the posterior surface of the left lobe of the liver. It is about 1.25 cm. in length, conical in shape and curved sharply to the left (fig. 1158), the base of the cone being continuous with the cardiac orifice of the stomach; its right border continues evenly into the lesser curvature of the stomach while its left border is separated from the fundus of the stomach by the cardiac notch (fig. 1178). It is covered with peritoneum in front and

FIG. 1159.—Longitudinal section through the upper part of the œsophagus.



on its left side; it is contained in the upper left part of the lesser omentum, the peritoneum reflected from its posterior surface to the Diaphragm being part of the gastro-phrenic ligament (p. 1407). The œsophageal branches of the left gastric vessels pass to the œsophagus in this peritoneal ligament. Behind the œsophagus are the left crus of the Diaphragm and the left phrenic artery. The vagus nerves have variable relations to the œsophagus as it passes through the Diaphragm.* Sometimes one trunk (consisting mainly of left vagal fibres) lies on the front, and one (consisting mainly of right vagal fibres) on the back of the œsophagus, but each vagus may consist of two or three trunks at this level.

Structure (fig. 1159).—The œsophagus has four coats: an external or fibrous, a muscular, a submucous or areolar, and an internal or mucous.

The *fibrous coat* consists of a layer of areolar tissue, containing many elastic fibres.

The *muscular coat* is composed of two layers of considerable thickness: an external of longitudinal and an internal of circular fibres.

The *longitudinal fibres* form a complete investment for nearly the whole of the œsophagus, but at the upper part of the back of the tube, at a point between 3 cm. and 4 cm. below the cricoid cartilage, they diverge from the median plane and form two longitudinal fasciculi which incline upwards and forwards to the front of the tube. Here they pass deep to the lower border of the Inferior constrictor muscle and end in a tendon which is attached to the upper part of the ridge on the posterior surface of the lamina of the cricoid cartilage (fig. 1088). The V-shaped interval between the diverging longitudinal fasciculi is filled by the circular fibres of the œsophagus, thinly covered below by some decussating longitudinal fibres, and above by the overlapping lower edge of the Inferior constrictor muscle. For the main part the longitudinal muscular coat of the œsophagus is thicker than the circular muscle coat.

Accessory slips of unstriped muscular fibres sometimes pass between the œsophagus and the left pleura, or between the œsophagus and the root of the left bronchus, trachea, pericardium, or aorta. These muscular slips help to fix the œsophagus to neighbouring structures.

The *circular fibres* are continuous superiorly, on the posterior surface, with the Inferior constrictor muscle; anteriorly, the uppermost are inserted into the lateral margins of the tendon of the two longitudinal fasciculi. Inferiorly, the circular muscle fibres are continuous with the oblique fibres of the stomach.

Radiological study shows that food is temporarily held up at the lower part of the œsophagus before passing into the stomach. This is attributed to the contraction of a 'physiological cardiac sphincter.' There is no localised thickening of the circular muscle of the œsophagus in this region. The delay may be due in part to the contraction of the surrounding muscle fibres of the Diaphragm, though some deny this.†

In man, striped muscle is generally limited to the upper two-thirds of the œsophagus; the lower third contains unstriped muscle only. (L. B. Arey and M. J.

* H. Doubilet G. P. Shafiroff and J. H. Mulholland *Annals of Surgery*, 127, 1948, 128-135.

† M. Atkinson, D. A. W. Edwards, A. J. Honour and E. N. Rowlands, *Lancet*, ii, 918, 1957.

Tremaine, 1933, *Anat. Rec.*, 56, 315.) In the upper quarter, both layers consist of striped muscle; in the second quarter bundles of smooth muscle appear and these gradually replace the striped muscle more caudally.

The *areolar* or *submucous coat* connects loosely the mucous and muscular coats. It contains the larger blood-vessels and nerves, as well as mucous glands.

The *mucous coat* is thick, of a reddish colour above, and pale below. It is disposed in longitudinal folds (Pl. XX), which disappear on distension of the tube. It consists of (1) a layer of stratified squamous epithelium, lining the tube, (2) a layer of connective tissue, papillae from which project into the epithelium, and (3) the *muscularis mucosæ*, a layer of longitudinally arranged non-striped muscular fibres. At the commencement of the *œsophagus* the *muscularis mucosæ* is absent, or only represented by a few scattered bundles; lower down it forms a considerable stratum. At the gastro-*œsophageal* junction the stratified squamous epithelium of the *œsophagus* is abruptly succeeded by the simple columnar epithelium of the stomach. The junction is visible to the naked eye in fresh preparations as a crenated line, the greyish-pink, smooth, *œsophageal* mucous membrane contrasting with the redder, mammillated, gastric *mucosa*.

The *œsophageal glands* are small, compound racemose glands of the mucous type; they are lodged in the submucous tissue outside the *muscularis mucosæ*, and each opens into the tube by a long duct which pierces the *muscularis mucosæ*. In the extreme upper and lower parts of the *œsophagus*, the glands resemble those in the cardiac part of the stomach (cardiac glands) and are situated between the *muscularis mucosæ* and the lumen of the gut.*

Vessels and Nerves.—The *arteries* supplying the *œsophagus* are derived from the inferior thyroid branch of the thyrocervical trunk, from the descending thoracic aorta, from the bronchial arteries, from the left gastric branch of the *cœliac* artery, and from the left phrenic branch of the abdominal aorta. They have for the most part a longitudinal direction. The *veins* from the cervical part of the *œsophagus* drain into the inferior thyroid veins and those from the thoracic part into the azygos vein. The abdominal part drains partly into the azygos vein and partly into the left gastric vein. The latter vein being a tributary of the portal vein, the abdominal part of the *œsophagus* is one of the sites where anastomoses between the portal and systemic veins occur (p. 876). In cases of obstruction of the portal circulation (e.g. in cirrhosis of the liver), these veins may become varicose and may burst into the lower part of the *œsophagus*, causing vomiting of blood and even fatal hæmorrhage. The *lymph vessels* are described on p. 912.

The nerves are derived from the vagus and sympathetic. The cervical part of the *œsophagus* receives branches from the recurrent laryngeal nerves and from the cervical sympathetic trunks (by means of the plexus around the inferior thyroid artery). The thoracic part has branches from the vagal trunks and *œsophageal* plexus, and from the sympathetic trunks and greater splanchnic nerves. The abdominal part (G. A. G. Mitchell, 1938, *Brit. J. Surgery*, 26, 333) is supplied by the vagal trunks (anterior and posterior gastric nerves), the thoracic sympathetic trunks, the greater (and occasionally the lesser) splanchnic nerves, and the plexus around the left gastric and phrenic arteries. The nerves form a plexus containing groups of ganglion-cells between the two layers of the muscular coat, and a second plexus in the submucous tissue.

Radiology (Pl. XX).—In oblique lateral views after a barium meal the main part of the thoracic portion of the *œsophagus* is seen in the 'retrocardiac space' behind the heart and diaphragm. The entire thoracic part is seen to be situated a little distance from the vertebral column, its lower part inclining forwards still further from the column. Its anterior wall is indented by the arch of the aorta, the left bronchus, and the left atrium, successively from above downwards. A thin layer of the barium meal may outline the longitudinal grooves of the mucous membrane.

THE ABDOMEN

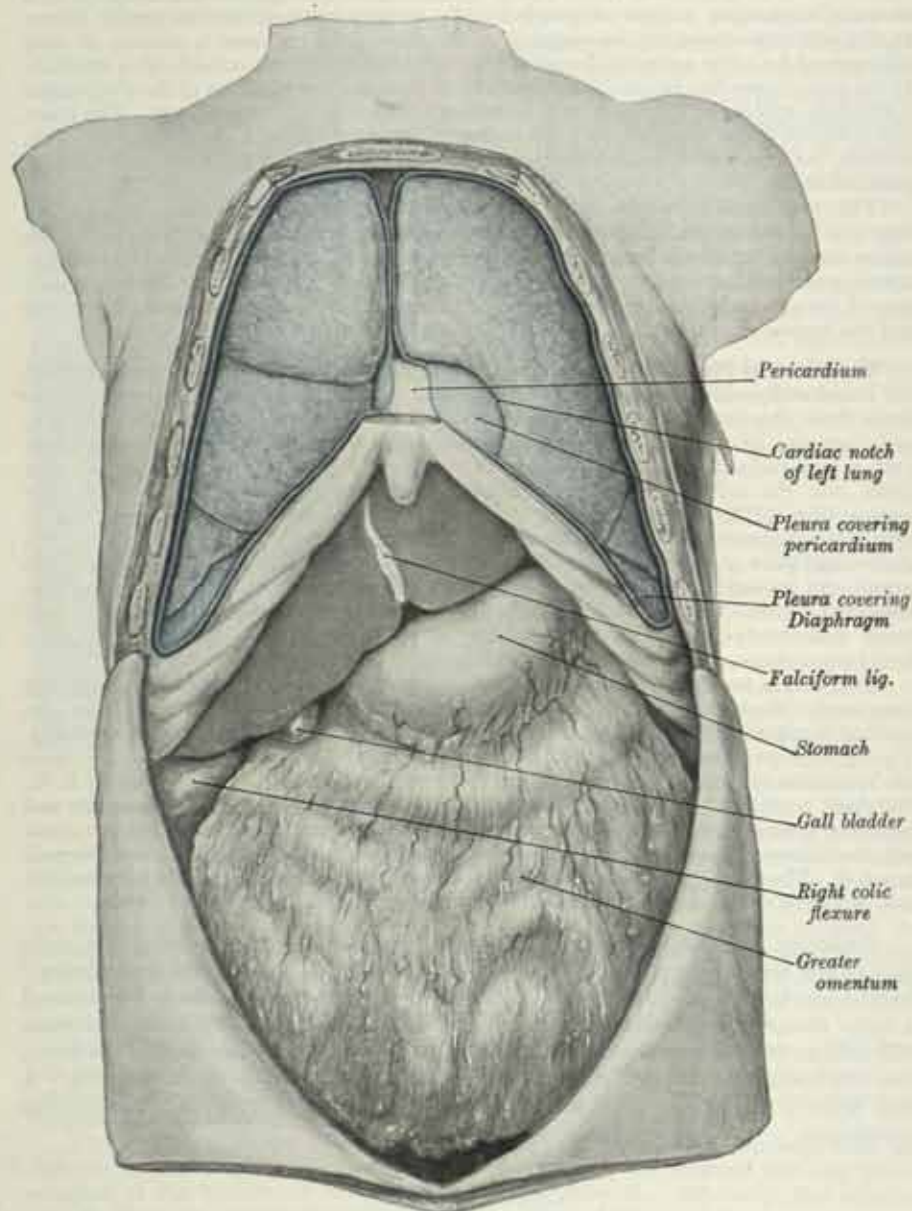
The abdomen is the region of the trunk that lies below the Diaphragm. It comprises an upper part, the *abdomen proper*, and a lower part, the *pelvis*. These two parts are continuous at the plane of the inlet of the pelvis, which is bounded by the promontory of the sacrum, the arcuate lines of the hip bones, the pubic crests and the upper border of the symphysis pubis. The abdomen is, to a large extent, bounded by muscles; consequently its shape and size can vary under different conditions, such as varying degrees of distension of the contained hollow organs and the

* B. A. E. Johns, *J. Anat., Lond.*, 1952, 86, 431.

phases of respiration. Further, the tone of these muscles is an important factor in maintaining the abdominal and pelvic viscera in position (pp. 598 and 605).

The *abdomen proper* is bounded *in front* by the Rectus abdominis muscles, the Pyramidales and the aponeurotic parts of the flat abdominal muscles (Obliquus externus abdominis, Obliquus internus abdominis and the Transversus abdominis);

FIG. 1160.—A front view of the thoracic and abdominal viscera.

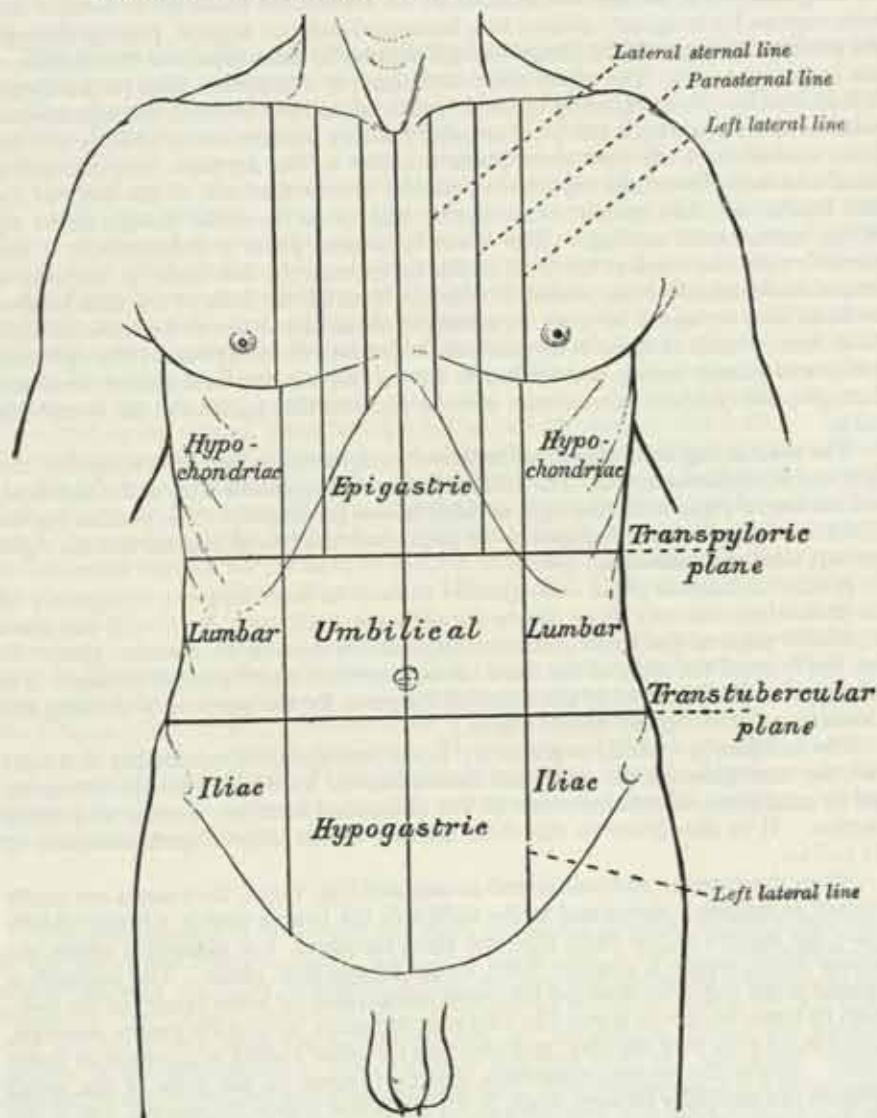


at the sides, by the fleshy parts of these flat abdominal muscles, the Iliacus muscles and the iliac bones; *behind*, by the lumbar part of the vertebral column, the crura of the Diaphragm, the Psoas and Quadratus lumborum muscles and the posterior parts of the iliac bones; and *above*, by the Diaphragm; while *below*, it is continuous with the pelvis through the inlet of the true pelvis (p. 403). As the Diaphragm, which forms the dome-like roof of the abdominal cavity, arches upwards so as to reach during expiration the level of the upper border of the fifth rib in the right lateral plane and the sixth rib in the left lateral plane, a considerable part of the abdominal

cavity extends upwards under cover of the bony framework of the thorax (*see pp. 586, 587 for variations in the position of the Diaphragm during respiration, etc.*). The abdomen proper contains the greater part of the digestive tube, as well as the liver, pancreas, spleen, kidneys, parts of the ureters, suprarenal glands and numerous blood-vessels, lymph vessels, lymph nodes and nerves.

The *pelvis* is funnel-shaped and extends backwards and downwards from the lower end of the abdominal cavity (figs. 1232, 1235). It is bounded *in front and at the sides*, by the parts of the hip bones below the pubic crests and arcuate lines,

FIG. 1161.—The surface lines on the front of the thorax and abdomen.



and by the Obturator internus muscles; *above and behind*, by the sacrum, coccyx and the Piriformis and Coccygeus muscles; and *below*, by the Levatores ani, which together with their covering fasciæ form the pelvic diaphragm (pp. 602 to 605), and by the Transversus perinei profundus and Sphincter urethræ, which together with their fascial coverings form the urogenital diaphragm. The pelvis contains the urinary bladder and part of the ureters, the sigmoid colon, rectum and a few coils of small intestine, and some of the generative organs, together with blood-vessels, lymph vessels, lymph nodes and nerves.

The muscles bounding the abdomen proper and the pelvis are, like muscles in

general, ensheathed in fascia; the layer of fascia covering the deep surface of the muscles immediately adjacent to the abdominal and pelvic cavities is named differently in the various regions. For example, that lining the internal surface of the Transversus abdominis is called the *transversalis fascia* (p. 599), that on the under surface of the Diaphragm is the *diaphragmatic fascia*, that covering the Psoas and Iliacus is the *iliac fascia* (p. 652), that covering the anterior surface of the Quadratus lumborum is the *anterior layer of the lumbar fascia* (p. 575), and that covering the muscles in the pelvis is the *pelvic fascia* (p. 602).

Most of the organs contained in the abdominal and pelvic cavities are largely covered with a serous membrane, termed the *peritoneum* (pp. 1399-1415).

Regions.—For purposes of location of the viscera the abdomen is divided into nine regions by imaginary planes, two horizontal and two sagittal, passing through the cavity, the edges of the planes being indicated by lines drawn on the surface of the body (fig. 1161). The upper horizontal plane, or *transpyloric plane* (of Addison), is indicated by a line encircling the body at a level midway between the suprasternal notch and the symphysis pubis (or roughly midway between the umbilicus and the lower end of the body—not the xiphoid process—of the sternum, or preferably a hand's breadth below the xiphisternal joint); it cuts the front of the body of the first lumbar vertebra near its lower border and meets the costal margin at the tip of the ninth costal cartilage. The lower horizontal plane is indicated by a line carried round the trunk at the level of the tubercle on the iliac crest (p. 393) and is termed the *transtubercular plane*; it cuts the front of the body of the fifth lumbar vertebra near its upper border. By means of these planes the abdomen is cut into three zones; each of these is further subdivided into three regions by the *right* and *left lateral planes*, which are indicated on the surface by lines drawn vertically through points halfway between the anterior superior iliac spines and the symphysis pubis.

The median region of the upper zone is the *epigastric*, and the lateral regions, the *right* and *left hypochondriac*. The median region of the middle zone is the *umbilical*, and the lateral regions are the *right* and *left lumbar* (or *lateral*). The median region of the lower zone is the *hypogastric* or *pubic*, and the lateral regions are the *right* and *left iliac* or *inguinal* (fig. 1161).

A third horizontal plane is frequently utilised in describing the topography of the abdominal viscera. It is drawn through the body on a level with the most dependent parts of the tenth costal cartilages and is termed the *subcostal plane*. It cuts the front of the body of the third lumbar vertebra near its upper border. It is frequently utilised instead of the transpyloric plane for the purpose of dividing the abdomen into the regions named above.

The *umbilicus* is variable in position; in the young adult it usually lies on a level with the disc between the third and fourth lumbar vertebræ. As age advances, and in conditions of deficient tone of the abdominal muscles, it sinks to a lower position. It is also lower in the child because of the undeveloped condition of the pelvis.

When the anterior abdominal wall is removed (fig. 1160), the viscera are partly exposed as follows: above and to the right side the liver is visible, situated chiefly under the shelter of the right ribs and their cartilages, but extending across the median plane, where it reaches down to the transpyloric plane. The stomach is exposed in the angle between the left costal margin and the lower border of the liver. From its lower border an apron-like fold of peritoneum, termed the *greater omentum*, descends for a varying distance, and obscures the other viscera to a greater or lesser extent. Below the greater omentum, however, some of the coils of the small intestine can generally be seen, while in the right iliac region the cæcum, and in the left iliac region the lower portion of the descending colon, are partly exposed (see p. 1408). The urinary bladder occupies the anterior part of the pelvis, and, if distended, projects above the symphysis pubis; the rectum is placed in the concavity of the sacrum, but is usually hidden by coils of the small intestine. The sigmoid colon may be seen lying between the rectum and the bladder.

When the stomach is followed from left to right, it is seen to be continuous with the first part of the small intestine [duodenum], the point of continuity being marked by a thickened ring (of muscle), which indicates the position of the pyloric sphincter. The duodenum passes towards the under surface of the liver, and then, curving downwards, is lost to sight. If, however, the greater omentum, together

with the transverse colon which lies beneath it, be thrown upwards over the chest, the inferior part of the duodenum can be traced across the vertebral column towards the left side, where it becomes continuous with the coils of the jejunum and ileum, which constitute the remainder of the small intestine. These measure about six metres in length (*see footnote, p. 1423*), and if followed downwards the ileum is seen to end in the right iliac fossa by opening into the large intestine at the junction of the cæcum and ascending colon. From the cæcum the large intestine takes an arched course, passing at first upwards on the right side, then across the median plane below the liver and stomach, and then downwards on the left side, forming respectively the ascending, transverse, and descending parts of the colon. In the pelvis the colon assumes the form of a loop, termed the sigmoid colon, and ends in the rectum.

The spleen lies behind the stomach in the left hypochondriac region, and may be exposed in part by pulling the stomach over towards the right side.

The glistening appearance of the deep surface of the abdominal wall and of the surfaces of the exposed viscera is due to the fact that the former is lined, and the latter are largely covered, with a serous membrane, termed the *peritoneum*.

The relations of the organs described in the following pages refer to the body in the recumbent position. But it must be remembered that the position of the viscera is affected not only by posture but by respiratory movements and by the condition of the hollow organs as regards quantity of contents. In addition there is a wide range of variation associated with bodily habitus, i.e. the shape of the chest, abdomen and pelvis, and, again, the organs may vary in the same individual at different times depending, for example, on their physiological activity and their degree of mobility. Thus, in the absence of radiological examination, the surface outlines of the viscera, particularly the hollow organs, described in the text and illustrated in the figures, must be regarded as variable within wide limits.

With regard to the different types of bodily habitus, individuals have been classified* into two extreme groups of body-build, namely, hypersthenic (or pyknic) and asthenic (or leptosomatic), with intermediate grades of sthenic and hyposthenic. In the hypersthenic type, with massive physique, the thorax is wide and short and the subcostal angle is very obtuse, so that the heart and lungs are wide transversely; the abdomen is widest in its upper part and the stomach is less elongated in a vertical direction with the pylorus relatively high, while the transverse colon is more truly transverse. In the asthenic type, with frail and slender physique, the thorax is long and narrow and the subcostal angle is acute, so that the heart and lungs are long and narrow; the abdomen is widest in its lower part, the stomach is long with the pylorus relatively low, while the colon is long with the transverse colon descending in a V-shaped manner to the pelvis. The varieties of human physique (somatotypes) have also been classified† as endomorphic (massive body-build), mesomorphic (intermediate) and ectomorphic (fragile), with intermediate grades, each type having predominant psychological characteristics.

THE PERITONEUM

The **peritoneum** is the largest and most complexly arranged serous membrane in the body, and consists, in the male, of a closed sac, a part of which lines the abdominal wall, while the remainder is reflected over the contained viscera. In the female the free ends of the uterine tubes open into the peritoneal cavity (Pl. XXXII). The portion which lines the abdominal wall (or parietes) is named the *parietal* portion of the peritoneum; that which is reflected over the contained viscera constitutes the *visceral* portion of the peritoneum. The *free surface* of the membrane is smooth, covered with a layer of flattened mesothelium and lubricated by a small quantity of serous fluid. Hence the viscera can glide on the wall of the cavity or on one another with a minimum of friction.

A considerable amount of areolar connective tissue intervenes between the parietal peritoneum and the abdominal parietes, with the fascial lining of which it blends. It is known as the *extraperitoneal tissue*. It varies in quantity and contains a varying amount of fat in different regions. While this tissue loosely connects the parietal peritoneum to the abdominal and pelvic walls in general and so allows the

* R. W. Mills, *Amer. J. Roentgen*, 1917, 4, 155; 1922, 9, 731.

† W. H. Sheldon, S. S. Stevens and W. B. Tucker, *The Varieties of Human Physique*, 1940, Harper and Brothers, Ltd., London.

peritoneum to be relatively easily stripped off these walls, it is denser on the under surface of the Diaphragm and behind the linea alba, so that the parietal peritoneum is more firmly adherent to these parts. It is especially loosely arranged in some places to allow of alteration in the size of certain organs; for example, in the front part of the pelvis and lower part of the anterior abdominal wall where it allows the urinary bladder to distend in an upward direction behind the anterior abdominal wall, from which it strips off the peritoneum as it ascends. It is usually heavily laden with fat on the posterior abdominal wall in relation to the kidneys. The visceral peritoneum, on the other hand, is firmly united to the viscera which it covers, and cannot be readily stripped off them. In fact, the connective tissue layer of the visceral peritoneum is directly continuous with the fibrous tissue stroma of the viscera; thus from the point of view of pathological conditions of an organ, the visceral peritoneum must be considered to be part of the viscus itself.

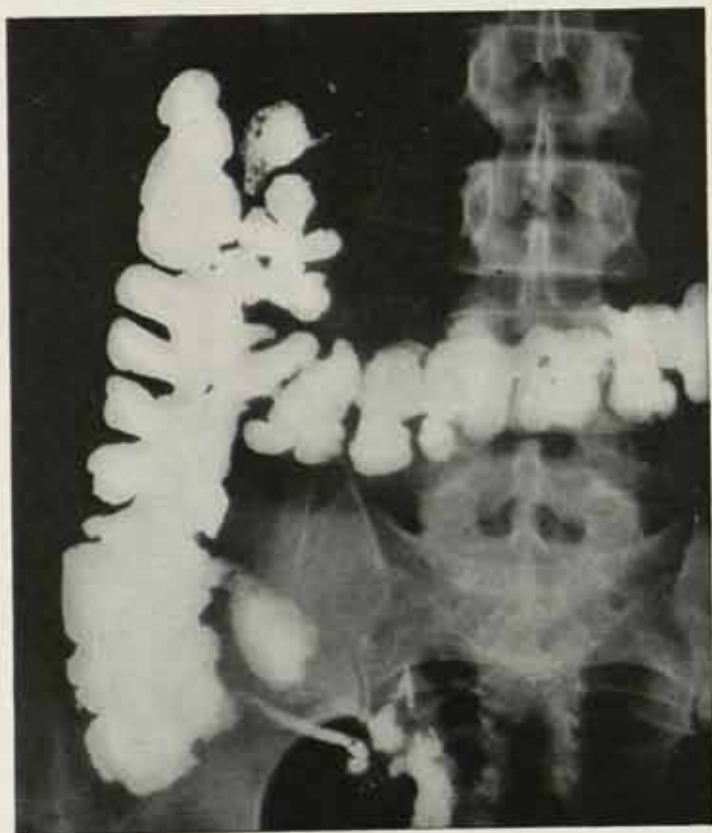
The parietal and visceral layers of the peritoneum are in actual contact, but the potential space between them is named the *peritoneal cavity*. The peritoneal cavity consists of (1) a main portion, termed the *greater sac* (or *cavum peritonei*), and (2) a diverticulum from this, termed the *omental bursa* or *lesser sac*, which is situated behind the stomach and adjoining structures; the neck or communication between the greater sac and the lesser sac is termed the *epiploic foramen* (or *aditus to the lesser sac*).

The disposition of the complexly arranged peritoneum is best understood by following the development of the digestive tube (pp. 188–196).

To trace the peritoneum from one viscus to another, and from the viscera to the parietes, it is necessary to follow its continuity in the vertical and horizontal directions, and it is simpler to describe the greater sac and the lesser sac separately.

Vertical disposition of the greater sac (fig. 1166).—It is convenient to commence tracing this from the anterior abdominal wall at the level of the umbilicus. A fibrous cord, termed the *ligamentum teres* or *obliterated umbilical vein* (p. 1458), runs upwards from the umbilicus to the inferior surface of the liver; it commences in the median plane at the umbilicus, inclines slightly to the right and recedes slightly from the anterior abdominal wall as it passes upwards; it raises a triangular fold of parietal peritoneum from the anterior abdominal wall and inferior surface of the Diaphragm in this upward course, the fold forming the *falciform ligament of the liver* (p. 1458 and fig. 1162). The latter consists of two layers of peritoneum, right and left, with connective tissue in between (figs. 1168, 1169). The lower part of the falciform ligament has a posterior free border, extending from the umbilicus to the lower border of the liver and containing the *ligamentum teres*, but the upper part extends from the Diaphragm to become continuous with the visceral peritoneum on the upper and anterior surfaces of the liver (fig. 1162). At the site of reflection from the anterior part of the inferior surface of the Diaphragm to the upper surface of the liver, the two layers of the falciform ligament diverge from each other (fig. 1209), the right layer passing more or less transversely to the right and forming the *superior layer of the coronary ligament of the liver* (which thus passes from the Diaphragm to the upper surface of the right lobe of the liver), while the left layer passes to the left to form the *anterior layer of the left triangular ligament of the liver* (which passes from the Diaphragm to the upper surface of the left lobe). The visceral peritoneum on the upper and anterior surfaces of the liver is continued round the sharp lower border of the liver to the inferior (visceral) surface of the organ, where it has the following relations: (a) To the right of the gall-bladder it covers the inferior surface of the right lobe and is reflected from the posterior part of this lobe to the right suprarenal gland and the upper end of the right kidney, forming the *inferior layer of the coronary ligament*; frequently the peritoneum passes directly from the inferior surface of the liver to the front of the right kidney, forming a fold termed the *hepatorenal ligament*. From the right kidney the peritoneum passes downwards to the front of the upper part of the duodenum and of the right colic flexure (fig. 1167); it also passes medially in front of a short segment of the inferior vena cava (between the duodenum and the liver), where it is continuous with the posterior wall of the omental bursa (fig. 1167). Between the two layers of the coronary ligament there is a large, triangular area on the back of the right lobe of the liver devoid of peritoneal covering; this is termed the *bare area* of the liver and here the liver is attached to the Diaphragm by areolar tissue. Towards the right margin of the liver the superior and inferior layers of the coronary ligament gradually

PLATE XXIX



Radiograph of part of the large intestine after a barium meal.

Note the vermiform appendix, which passes from the medial side of the caecum medially and slightly downwards into the pelvis. At a slightly higher level the terminal part of the ileum can be recognised. The first part of the transverse colon runs downwards in front of, and slightly medial to, the ascending colon, before it turns to the left.

PLATE XXX



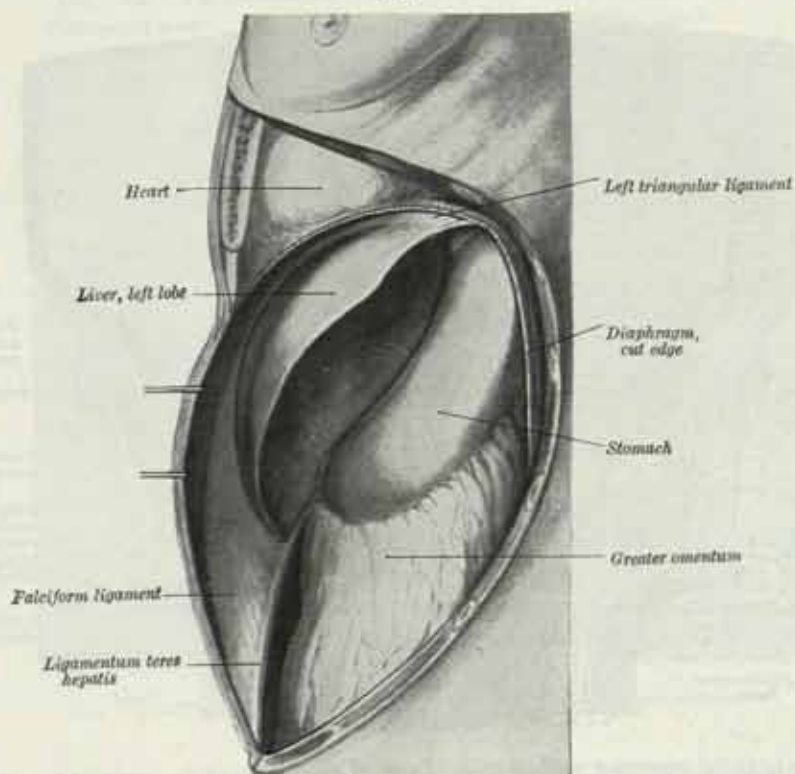
Radiograph taken 17 hours after the oral administration of sodium tetraiodo-phenolphthaleine. (Cholecystogram : Dr. J. L. A. Grout.)

- | | |
|----------------------------|--------------------------------|
| 1. Fundus of gall-bladder. | 2. Neck of gall-bladder. |
| 3. Bile duct. | 4. Gas in right colic flexure. |

Note the relation of the bile duct to the transverse processes of the second and third lumbar vertebrae.

approach each other and ultimately fuse to form a small triangular fold, connecting the right lobe of the liver to the Diaphragm and called the *right triangular ligament* of the liver (fig. 1210). The latter forms the apex of the bare area, the base being formed by the *groove for the inferior vena cava*. (b) The visceral peritoneum covers the inferior surface and sides of the gall-bladder, the inferior surface of the quadrate lobe of the liver as far back as the anterior margin of the porta hepatis, and the inferior surface of the left lobe; from the posterior border of the left lobe it is reflected to the Diaphragm as the *posterior layer of the left triangular ligament*. The peritoneum along the anterior margin of the porta hepatis is continuous at the right extremity of the porta with the peritoneum of the omental bursa, the latter being reflected from the posterior margin of the porta (fig. 1210). The visceral peritoneum passes into the depth of the fissure for the ligamentum venosum (fig. 1210), between the caudate and left lobes of the liver, in two layers, anterior and posterior. The anterior

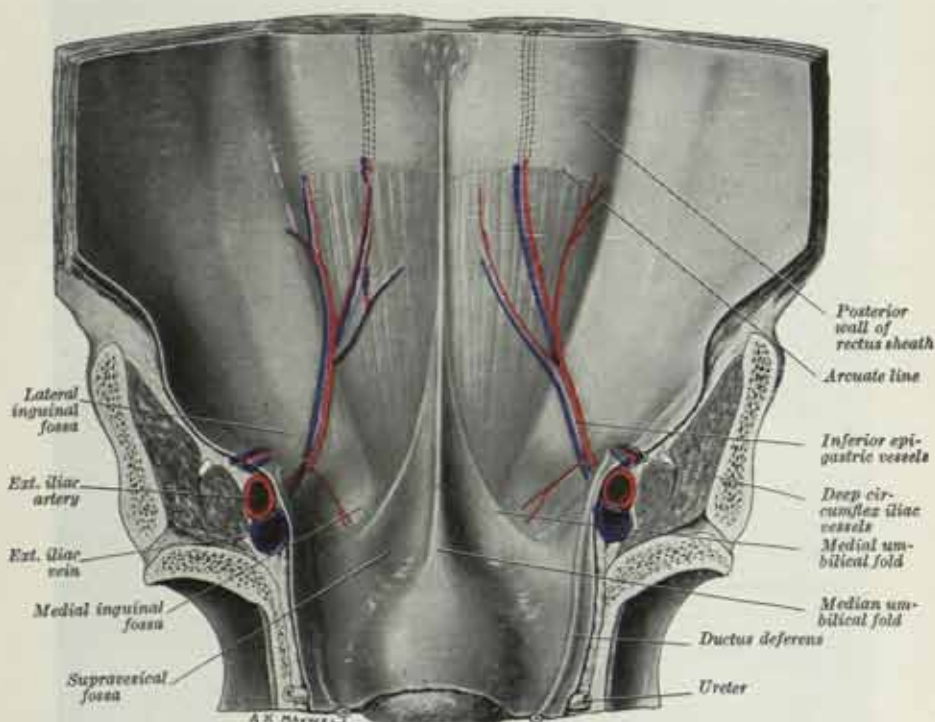
FIG. 1162.—A dissection to expose the left side of the falciform ligament of the liver.



layer is continuous with the peritoneum reflected from the anterior margin of the porta hepatis (fig. 1210). From this J-shaped line formed by the left margin of the fissure for the ligamentum venosum and the anterior margin of the porta hepatis, the peritoneum is reflected to the lesser curvature of the stomach and the first 2 cm., or less, of the duodenum forming the anterior layer of the *lesser omentum*. The part of the lesser omentum connecting the liver to the stomach is called the *hepatogastric ligament*, while the part passing from the liver to the duodenum is named the *hepatoduodenal ligament*. The anterior layer of the lesser omentum, if traced to the right, is found to pass in front of the hepatic artery, bile duct and portal vein, and then to turn round the right side of these structures to become continuous behind them with the posterior layer of the lesser omentum; the latter here forms the anterior wall of the omental bursa. Thus the lesser omentum has a free right border, in which lie the hepatic artery, bile duct and portal vein, and behind which is the *epiploic foramen* (fig. 1168). The anterior layer of the lesser omentum is continuous below with the visceral peritoneum that covers the front of the stomach and the first 2 cm. of the duodenum. This layer of peritoneum then descends from the greater

curvature of the stomach and the neighbouring part of the duodenum to form the most anterior layer of a large free fold, called the *greater omentum*. Reaching the free lower margin of this fold, it turns upwards, forming the most posterior layer of the greater omentum; the latter runs to the anterosuperior aspect of the transverse colon (opposite the *tænia omentalis*), to which it is adherent but from which it can be stripped off. It then passes backwards, adherent to but separable from the upper layer of the transverse mesocolon, to the anterior surface of the head and the upper border of the body of the pancreas, whence it passes down over the anterior surface of the pancreas as far as the anterior border of the body of that organ; it leaves the latter as the upper layer of the transverse mesocolon (fig. 1166). This passes to the posterior surface of the transverse colon (opposite the *tænia mesocolica*), covers the upper, anterior and lower surfaces of that part of the gut, and

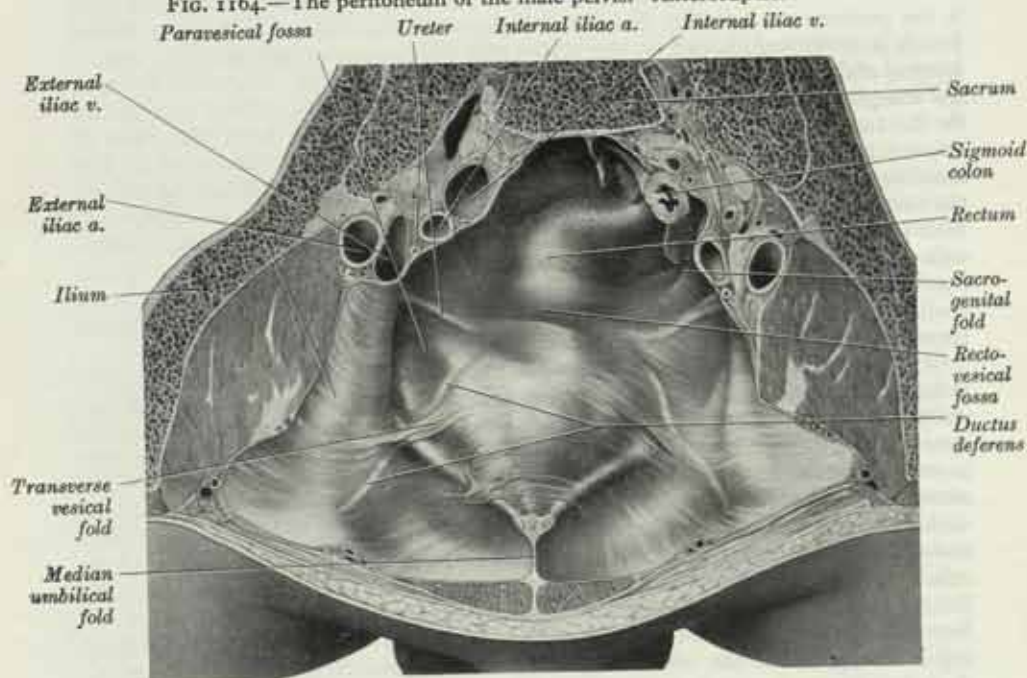
FIG. 1163.—The lower part of the anterior abdominal wall of a male subject. Posterior surface, with the peritoneum in place.



passes from its posterior surface to the front of the head and the anterior border of the body of the pancreas as the inferior layer of the transverse mesocolon. Thence it is continued over the lower part of the anterior surface of the head and over the inferior surface of the body of the pancreas on to the front of the third and fourth parts of the duodenum. From the latter it passes downwards on the posterior abdominal wall; it is also in part carried forward on the superior mesenteric vessels to the jejunum and ileum as the *right layer of the mesentery*. It invests this part of the gut and then passes to the posterior abdominal wall as the *left layer of the mesentery*; it then descends over structures like the abdominal aorta, inferior vena cava, the ureter and the Psoas major into the pelvis. It is reflected from the posterior pelvic wall, as the anterior layer of the *sigmoid mesocolon*, invests the sigmoid colon and then returns to the pelvic wall as the posterior layer of the sigmoid mesocolon. It then descends, covering the front and sides of the upper third of the rectum and the front of the middle third of the rectum. *In the male*, it leaves the front of the rectum (at the junction of its middle and lower thirds) and passes forwards on to the upper ends of the seminal vesicles and the upper surface of the urinary bladder. Between the rectum and bladder it dips slightly downwards forming a pouch, the *recto-vesical pouch*, the bottom of which is a little below the level of the upper ends of the

seminal vesicles and about 7.5 cm. from the anal orifice. From the apex of the bladder it is carried along the median and medial umbilical ligaments (fig. 1163) to the anterior abdominal wall up to the level of the umbilicus (from which a start was made). When the bladder is distended the peritoneum is stripped away from the lower part of the anterior abdominal wall, so that a considerable part of the anterior surface of the bladder lies directly against the abdominal wall without the intervention of peritoneum (p. 1484). An instrument can therefore be passed through the abdominal wall into the distended bladder without passing through the peritoneal cavity. In the female, the peritoneum passes from the front of the rectum on to the posterior fornix of the vagina and thence on to the back of the cervix and body of the uterus, forming the *rectouterine fold*. This fold dips downwards to form the *recto-uterine pouch*, the bottom of which is about 5.5 cm. from the anal orifice. The peritoneum continues over the fundus of the uterus and descends on its anterior (vesical) surface as far as the junction of the body and cervix, from which site it is

FIG. 1164.—The peritoneum of the male pelvis. Anterosuperior view.



Note. The median umbilical fold contains both the median and the lateral umbilical ligaments in the plane of section in this subject.

reflected forwards on to the upper surface of the bladder, forming a shallow pouch, the *vesico-uterine pouch*. The layers of peritoneum on the anterior and posterior surfaces of the uterus are reflected laterally, from the lateral margins of the uterus, to the side walls of the pelvis, forming on each side an expanded fold, termed the *broad ligament of the uterus*; the latter thus consists of two layers of peritoneum, anterior and posterior, which are continuous above to form the free upper border of the broad ligament; between the two layers at the upper border is the uterine tube. The reflection of the peritoneum from the bladder to the anterior abdominal wall is similar to that in the male.

Horizontal disposition of the greater sac.—Below the transverse colon the arrangement is simple, and it may be considered in the two regions, viz. in the pelvis and in the abdomen proper.

(1) *In the pelvis.*—The peritoneum here follows closely the surfaces of the pelvic viscera and the inequalities of the pelvic walls, and presents important differences in the two sexes. (a) *In the male* (fig. 1164) it encircles the sigmoid colon, from which it is reflected to the posterior wall of the pelvis as a fold, termed the *sigmoid mesocolon*. It leaves the sides and, finally, the front of the rectum, and is continued over the upper parts of the seminal vesicles to the upper surface of the bladder; on each side

of the rectum it forms a *pararectal fossa*, which varies in size with the distension of the rectum. In front of the rectum the peritoneum forms the recto-vesical pouch, which is limited laterally by peritoneal folds extending from the sides of the bladder backwards, on either side of the rectum, to the front of the sacrum. These folds are known, from their position, as the *sacrogenital folds*. The peritoneum of the anterior pelvic wall covers the superior surface of the bladder, and on each side of this viscus forms a depression, termed the *paravesical fossa*, which is limited laterally by the fold of peritoneum covering the ductus deferens. The size of this fossa is dependent on the state of distension of the bladder, and when the bladder is empty, a variable fold of peritoneum, termed the *transverse vesical fold*, divides the fossa into two portions. Under the same conditions, the anterior ends of the sacrogenital folds may sometimes be joined by a fold which demarcates an anterior part of the recto-vesical pouch, termed the middle fossa (fig. 1164). On the peritoneum between the paravesical and pararectal fossæ the only elevations are those produced by the ureters and the internal iliac vessels. (b) *In the female*, pararectal and paravesical fossæ similar to those in the male are present; the lateral limit of the paravesical fossa is the peritoneum investing the round ligament of the uterus. The recto-vesical pouch is, however, divided by the uterus and vagina into a small, anterior, vesico-uterine and a deep, posterior, recto-uterine pouch (fig. 1235). The folds forming the margins of the latter are the *recto-uterine folds* (p. 1519); they correspond to the sacrogenital folds of the male, and pass backwards from the sides of the cervix uteri, on either side of the rectum, to the front of the sacrum. The *broad ligaments* extend from the sides of the uterus to the lateral walls of the pelvis; the uterine tubes are contained in their free margins, and the ovaries are attached to their posterior layers. Below, the broad ligaments are continuous with the peritoneum on the lateral walls of the pelvis. In the angle between the elevations produced by the obliterated umbilical artery and the ureter on the lateral pelvic wall, there is a shallow fossa, known as the *ovarian fossa*, in which the ovary lies in the nulliparous female. It is situated behind the lateral attachment of the broad ligament.

(2) *In the lower abdomen*.—The peritoneum lining the lower part of the anterior abdominal wall is raised into five ridges or folds which converge as they pass upwards (fig. 1163). One of these is placed in the median plane and extends from the apex of the urinary bladder to the umbilicus. It contains the urachus (p. 217) and is termed the *median umbilical fold*. To its lateral side the obliterated umbilical artery forms the *medial umbilical fold*, as it ascends from the pelvis towards the umbilicus. The depression between the two umbilical folds is termed the *supravesical fossa*. Further to the lateral side, the inferior epigastric artery raises a fold, called the *lateral umbilical fold*, below the point at which it enters the sheath of the Rectus muscle. The *medial inguinal fossa* is the depression situated between the lateral and medial umbilical folds; the *lateral inguinal fossa*, which overlies the deep inguinal ring, lies to the lateral side of the lateral umbilical fold and indicates the site where the processus vaginalis extended into the anterior abdominal wall during the descent of the testis. A fourth depression is placed below and slightly medial to the lateral inguinal fossa and is separated from it by the medial end of the inguinal ligament. It overlies the femoral ring (p. 818) and is termed the *femoral fossa*.

Traced from the linea alba, below the level of the transverse colon, and followed in a horizontal direction to the right, the peritoneum covers the inner surface of the abdominal wall almost as far as the lateral border of the Quadratus lumborum; it is reflected over the sides and front of the ascending colon and encloses the cæcum and vermiform appendix; it may then be traced over the duodenum, Psoas major, and inferior vena cava towards the median plane, whence it passes along the mesenteric vessels to invest the small intestine, and back again to the large vessels in front of the vertebral column, forming the *mesentery* (figs. 1166 and 1167), the layers of which enclose the jejunum, ileum, the superior mesenteric blood-vessels, nerves, lacteals and lymph nodes. It is then continued over the left Psoas major; it covers the sides and front of the descending colon, and, reaching the abdominal wall, is carried on it to the median plane.

(3) *In the upper abdomen* (figs. 1167, 1168).—Above the transverse colon, the peritoneum of the greater sac is more complexly arranged. Starting in front of the part of the inferior vena cava lying immediately above the first part of the duodenum, the peritoneum of the greater sac is here continuous to the left, behind the epiploic foramen, with the peritoneum forming the posterior wall of the omental bursa

(fig. 1168). From the front of the inferior vena cava, it passes to the right over the front of the right suprarenal gland and upper part of the right kidney to the anterolateral abdominal wall. From the anterior median line a double fold passes backwards and to the right, to become continuous with the peritoneum investing the liver, and forms the *falciform ligament*. Continuing to the left, the peritoneum lines the anterolateral abdominal wall and covers the lateral part of the front of the left kidney, and is thence reflected to the posterior border of the hilum of the spleen as the posterior or lateral layer of the *lienorenal* (or *phrenico-lienal*) *ligament* (fig. 1168). It can then be traced over the surfaces of the spleen to the front of its hilum, and thence to the cardiac end of the greater curvature of the stomach as the left layer of the *gastrosplenic ligament*. It covers the anterosuperior surface of the stomach and commencement of the duodenum, and ascends from the lesser curvature of the stomach to the liver as the anterior layer of the lesser omentum. The right free border of the latter has been previously described (p. 1401), and at this border the anterior layer of the lesser omentum (formed by peritoneum of the greater sac) becomes continuous with the posterior layer of the lesser omentum (formed by the peritoneum of the omental bursa).

The omental bursa.—The *omental bursa*, or lesser sac of the peritoneum, is a large recess of irregular outline which lies behind the stomach and extends beyond its limits. Its anterior and posterior walls are extensive and they are limited by variable lower, right, left and upper borders. The recess is completely shut off from the greater sac except in the upper part of its right border where a communication is established through a slit-like opening. In its upper part the posterior wall of the lesser sac is formed by a single layer of peritoneum, closely applied to the posterior abdominal wall (fig. 1166), but, below the pancreas, the sac is carried into the interior of the greater omentum and its posterior wall is formed by the posterior two layers of that structure, which, above the transverse colon, are adherent to the transverse mesocolon (fig. 1166).

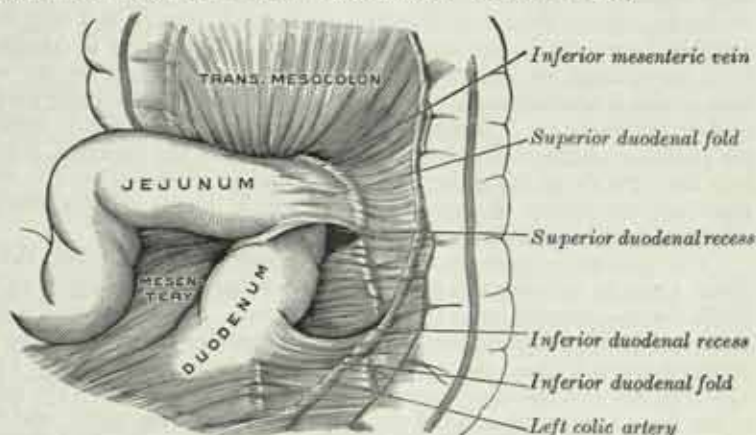
The *epiploic foramen* (or *aditus* to the lesser sac) is a short, slit-like passage, about 3 cm. in its vertical length, which leads out from the upper part of the right border of the omental bursa into the greater sac. Its *anterior wall* is formed by the right margin of the lesser omentum, which contains between its two layers in this situation the bile-duct, the portal vein and the hepatic artery (fig. 1168). Traced upwards, the two layers separate and the posterior layer covers the caudate process of the liver, forming the *roof* of the epiploic foramen (fig. 1170), and then descends in front of the inferior vena cava, forming the *posterior wall* of the foramen. At, or a little below, the upper border of the first part of the duodenum, this layer passes forwards from the front of the inferior vena cava and above the head of the pancreas to become continuous with the posterior layer of the lesser omentum, and in this situation, it forms the *floor* of the epiploic foramen. The medial end of the floor is continuous inferiorly with the right border of the lower part of the omental bursa (fig. 1167), and it is by passing forwards below the medial end of the floor that the hepatic artery is able to insinuate itself between the two layers of the lesser omentum (fig. 1168). The narrow passage lying to the left of the epiploic foramen, below the caudate process of the liver and above the first part of the duodenum, is called the *vestibule* of the omental bursa. Traced laterally, i.e. to the right, all the boundaries of the epiploic foramen become continuous with peritoneum of the greater sac. The roof is continuous with the peritoneal covering of the inferior surface of the right lobe of the liver (fig. 1210); the posterior wall with the peritoneum on the right suprarenal gland (fig. 1167); the anterior wall with the anterior layer of the lesser omentum round the portal vein and the bile-duct (fig. 1168); the floor with the peritoneum covering the lower part of the right suprarenal gland and the adjacent parts of the duodenum and right kidney (fig. 1167). The anterior and posterior walls of the epiploic foramen are normally in contact with each other.

The *omental bursa* and its boundaries can now be considered in detail. The *anterior wall* is formed (1) by the peritoneum which covers the postero-inferior aspect of the stomach and the first 2 cm., or less, of the duodenum. Traced downwards this layer becomes the posterior of the anterior two layers of (2) the greater omentum; traced upwards and to the right, it leaves the stomach along the lesser curvature and the duodenum at its upper border, and becomes the posterior layer of (3) the lesser omentum. The omental bursa is usually described as passing upwards

behind the caudate lobe of the liver, but this description is scarcely accurate, for the caudate lobe projects into the omental bursa from its right border and is covered by peritoneum on its anterior as well as on its posterior surface (figs. 1166 and 1210).

The *posterior wall* is formed by the anterior of the posterior two layers of the greater omentum. Above, the posterior of these two layers is fused with, but separable from, the peritoneum on the upper aspect of the transverse colon and the upper layer of the transverse mesocolon. The surgeon can thus separate the omentum from the transverse colon and its mesocolon and in this way gain access to the posterior wall of the stomach through the posterior wall (greater omentum) of the omental bursa. A transverse incision at the place where the omentum meets the transverse colon opens up the embryological plane ('bloodless plane') of adhesion of the omentum to the colon and its mesocolon and thus passes between the omental vessels (from the gastro-epiploic vessels) in the greater omentum and the middle colic vessels in the transverse mesocolon.* There are no anastomoses between the omental and colic vessels across the plane of embryological adhesion of the omentum and transverse mesocolon. Above the anterior border of the

FIG. 1165.—The superior and inferior duodenal recesses. (After Jonnesco.) From Poirier and Charpy's *Traité d'Anatomie humaine*. (Masson et Cie.)



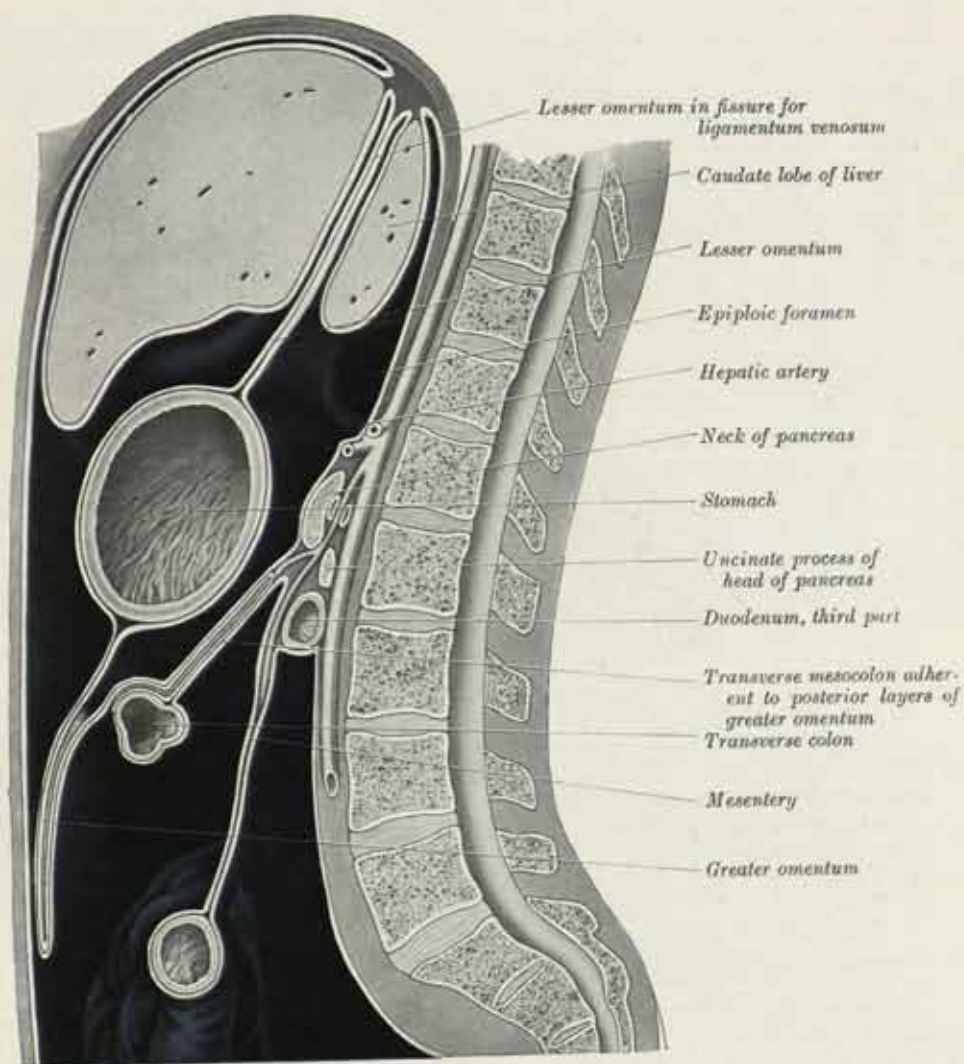
pancreas, the posterior wall of the omental bursa lines the posterior abdominal wall, covering a small part of the front of the head, and the whole of the front of the neck and body of the pancreas, a small part of the anterior aspect of the left kidney and most of the anterior aspect of the left suprarenal gland, the commencement of the abdominal aorta and the celiac artery, and a considerable area of the Diaphragm. In addition, the phrenic, the splenic, the left gastric and, to a much smaller extent, the hepatic arteries course behind the omental bursa (figs. 1167 and 1168).

The borders of the omental bursa are formed by the lines along which the peritoneal posterior wall is reflected to become continuous with the peritoneal anterior wall, and they are subject to considerable variation. The *lower border* is, developmentally (p. 191), the lower border of the greater omentum, but, as a rule, partial fusion of the constituent layers of the greater omentum occurs after birth, so that *the cavity of the omental bursa in the adult does not usually extend much below the transverse colon*. The *upper border* of the omental bursa is narrow and extends between the right side of the œsophagus and the upper end of the fissure for the ligamentum venosum of the liver (fig. 1210). In this interval the peritoneal posterior wall of the omental bursa is reflected forwards from the Diaphragm and becomes continuous with the posterior layer of the lesser omentum.

The *right border* of the omental bursa corresponds, below, to the right free border of the greater omentum. Above the upper end of the latter it is formed by the reflexion of the peritoneum from the neck and head of the pancreas on to the posterior surface of the first part of the duodenum (fig. 1169). The line of this

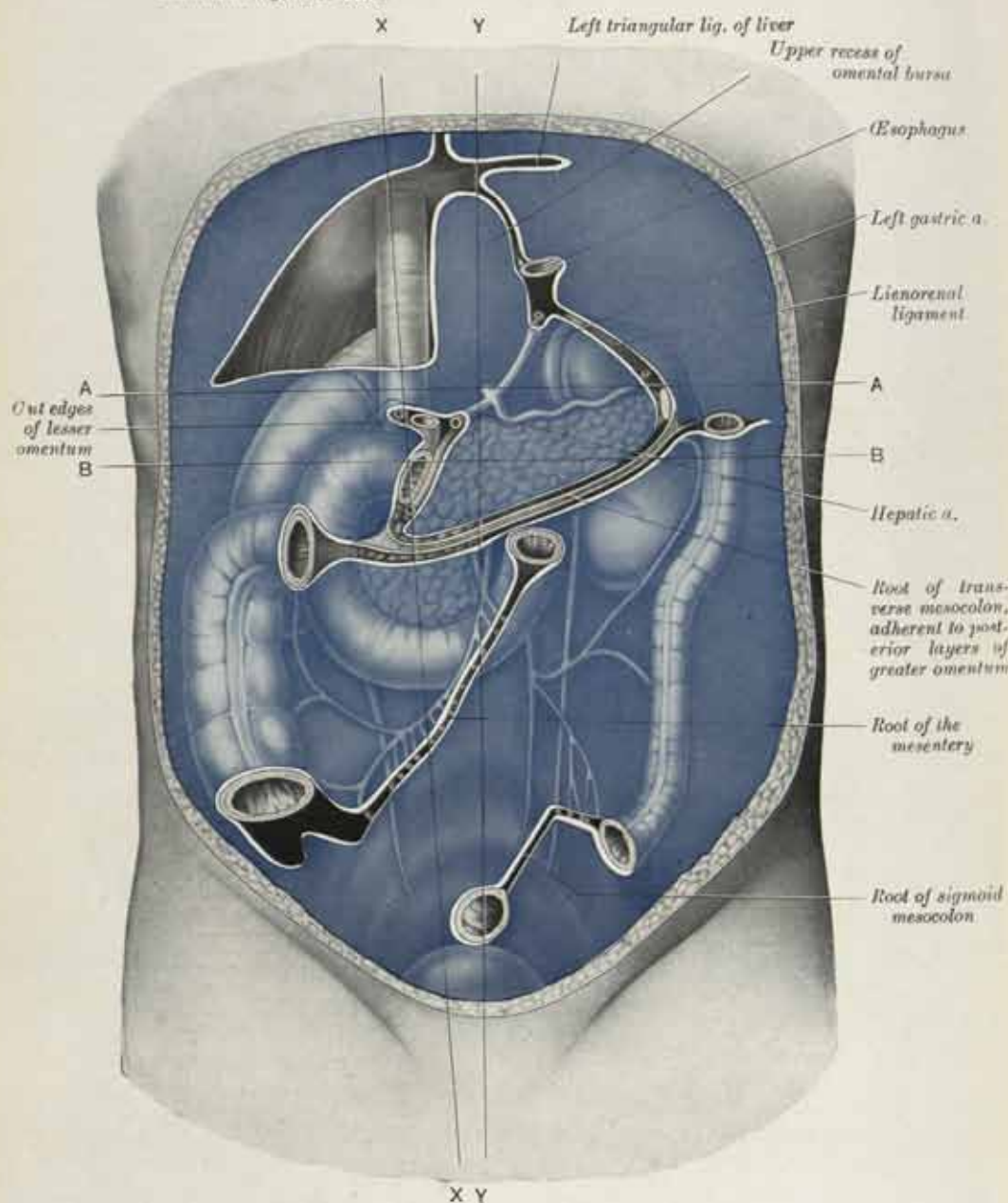
* P. Fredet, in Poirier and Charpy, *Traité d'Anatomie Humaine*, Paris, 1905, vol. 4, pp. 962-964; G. Lardennois and J. Okinczyc, *Bull. et Mem. Soc. Anat. de Paris*, 1913, 15, 429-434; R. Grégoire, *Anatomie Médico-Chirurgicale de l'Abdomen*, Paris, 1922, p. 149; W. H. Ogilvie, *Brit. Med. J.*, i, p. 457, 1935.

FIG. 1166.—A sagittal section through the abdomen, approximately in the median plane. Diagrammatic. Compare with Fig. 1167.



The section cuts the posterior abdominal wall along the line YY in Fig. 1167. The peritoneum is shown in *blue* except along the cut edges, which are left *white*.

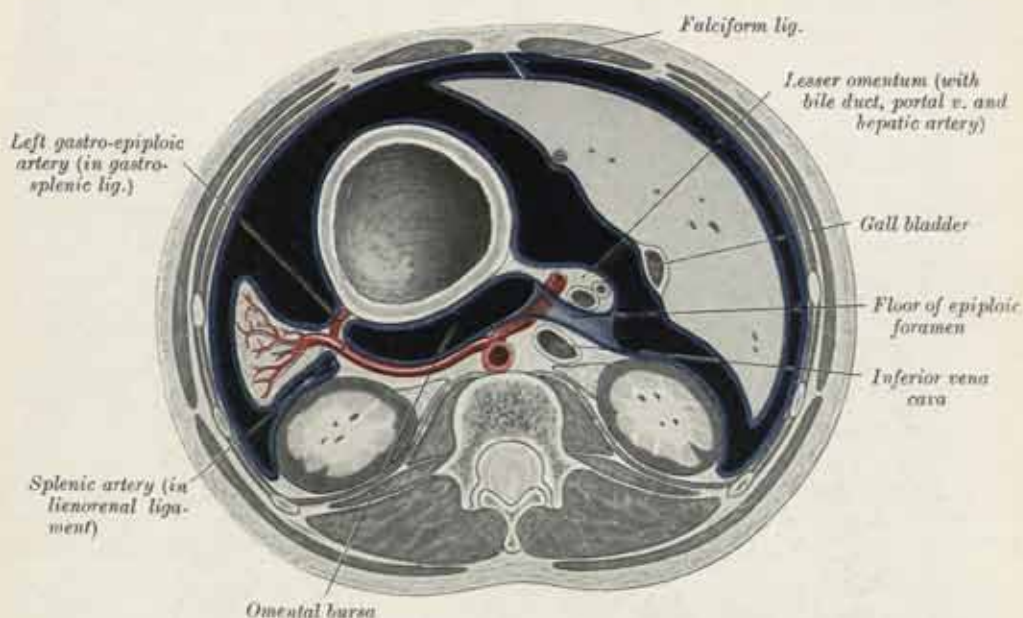
FIG. 1167.—The posterior abdominal wall, showing the lines of peritoneal reflexion, after removal of the liver, spleen, stomach, jejunum, ileum, cæcum, transverse colon and sigmoid colon.



Line YY represents the plane of Fig. 1166.
Line XX represents the plane of Fig. 1170.

Line AA represents the plane of Fig. 1168.
Line BB represents the plane of Fig. 1169.

FIG. 1168.—A transverse section through the abdomen, at the level of line AA, Fig. 1167, viewed from above. Diagrammatic.



The peritoneal cavity is shown in dark blue ; the peritoneum and its cut edges in lighter blue.

FIG. 1169.—A transverse section through the abdomen, at the level of the line BB in Fig. 1167, viewed from above. Diagrammatic. Colours as in Fig. 1168.

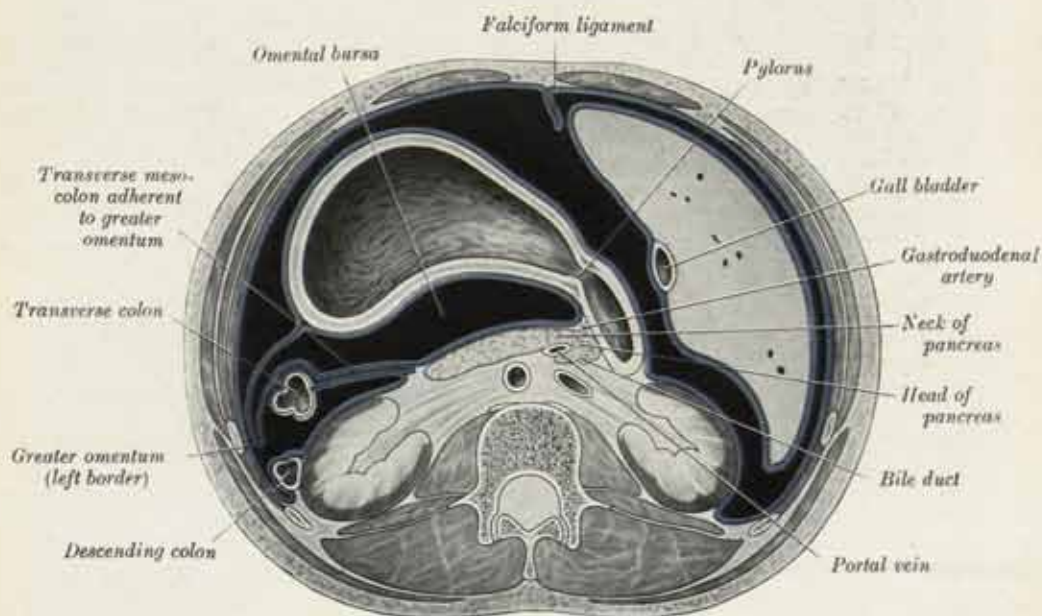
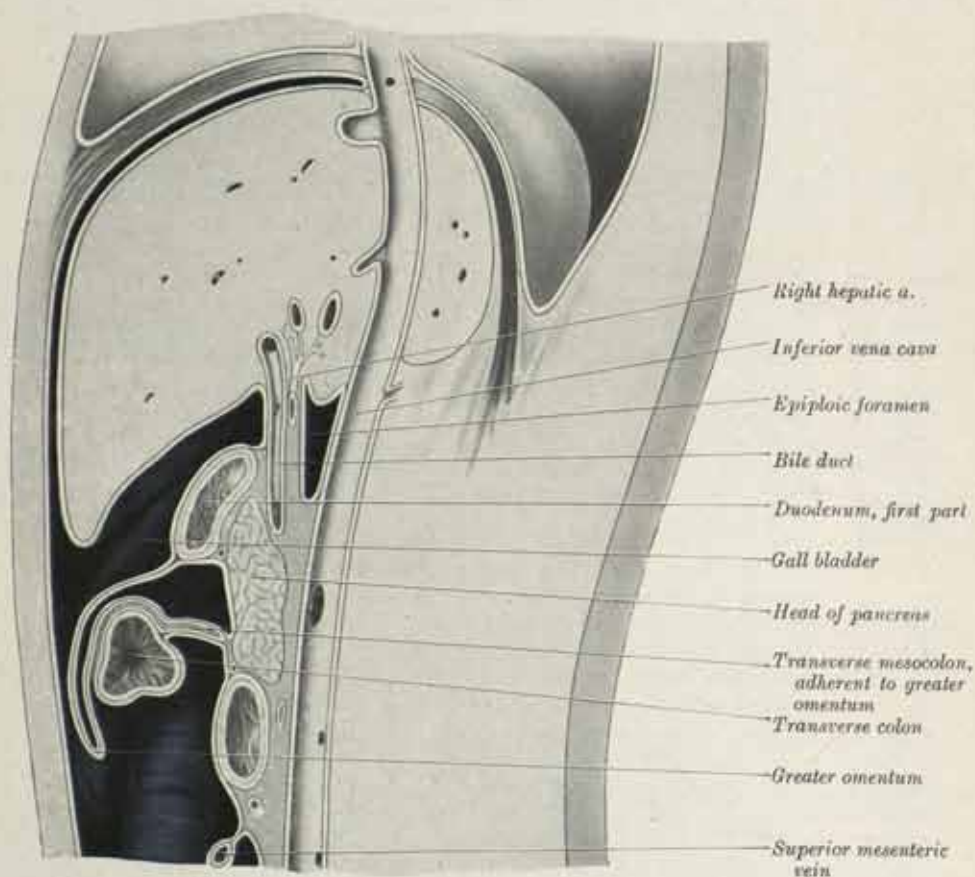


FIG. 1170.—A section through the upper part of the abdominal cavity, along the line XX in Fig. 1167.



The boundaries of the epiploic foramen are shown, and a small recess of the omental bursa is displayed in front of the head of the pancreas. Note that the transverse colon and its mesocolon are adherent to the posterior two layers of the greater omentum.

reflexion passes upwards and to the left along the medial side of the gastroduodenal artery. Near the upper border of the duodenum the right border becomes continuous with the floor of the epiploic foramen round the hepatic artery (fig. 1167). Above the opening, which interrupts its continuity, the right border is formed by the reflexion of the peritoneum from the Diaphragm to the right margin of the caudate lobe of the liver and it follows the left edge of the inferior vena cava (fig. 1167).

The *left border* of the omental bursa is formed, below, by the left free margin of the greater omentum. Above the root of the transverse mesocolon (fig. 1167) the left border is broader. It is formed by the *lienorenal* and the *gastrosplenic ligaments* (fig. 1168), which together represent a part of the original dorsal mesogastrium (p. 197). The lienorenal ligament extends from the front of the left kidney to the hilus of the spleen as a two-layered fold, in which the splenic vessels and the tail of the pancreas (figs. 1167 and 1168) are enclosed. From the hilus of the spleen these two layers are continued forwards to the greater curvature of the stomach as the gastrosplenic ligament. The inner (or right) layer of the lienorenal ligament is directly continued into the inner (or right) layer of the gastrosplenic ligament; but the outer (or left) layer of the lienorenal ligament, on reaching the back of the hilus of the spleen, is continuous with the visceral peritoneum which surrounds the spleen. The latter is then reflected from the front of the hilus of the spleen as the outer (or left) layer of the gastrosplenic ligament. The spleen thus projects to the left into the greater sac (fig. 1168). The part of the omental bursa projecting towards the spleen, between the lienorenal and gastrosplenic ligaments, is known as the *splenic recess* of the omental bursa. At their upper ends the lienorenal and the gastrosplenic ligaments merge into a short fold, termed the *gastrophrenic ligament*, which passes from the Diaphragm, behind, to the posterior aspect of the fundus of the stomach, in front. The two layers of this ligament diverge as they approach the oesophagus and a part of the posterior surface of the stomach is left devoid of peritoneal covering (fig. 1167). In this situation the upper end of the left border becomes continuous with the left extremity of the roof and the left gastric artery turns forwards to gain the lesser omentum.

The interior of the omental bursa is encroached on by two sickle-shaped folds of peritoneum which are drawn into the sac by the hepatic and left gastric arteries. The upper or *left gastropancreatic fold* is formed by the left gastric artery as it passes from the posterior abdominal wall to reach the lesser curvature of the stomach; the lower or *right gastropancreatic fold* is formed by the hepatic artery as it passes forwards from the posterior abdominal wall to gain the lesser omentum (fig. 1167). The folds show considerable variation in their depths but, when well marked, they constrict the lesser sac and enclose a foramen which is sometimes called the *foramen bursae omenti majoris*. The *superior recess* of the omental bursa lies above the foramen and communicates through it with the *inferior recess*, which represents the true *bursa omentalis* of the embryo (p. 196). The superior recess thus lies behind the lesser omentum and the liver, while the inferior recess lies behind the stomach and in the greater omentum.

During a considerable part of foetal life the transverse colon is suspended from the posterior abdominal wall by a mesentery of its own, the posterior two layers of the greater omentum passing at this stage in front of the colon (fig. 205). This condition occasionally persists throughout life, but as a rule adhesion occurs between the mesentery of the transverse colon and the posterior layer of the greater omentum; even so, these layers of peritoneum are separable in the adult (more readily in the living subject than in the formalinised cadaver) (see pp. 1402, 1406). In the adult the omental bursa intervenes between the stomach and the structures on which that viscus lies and which form the 'stomach bed' (p. 1417); it performs therefore the functions of a serous bursa for the stomach, facilitating the movements of the latter over the neighbouring structures.

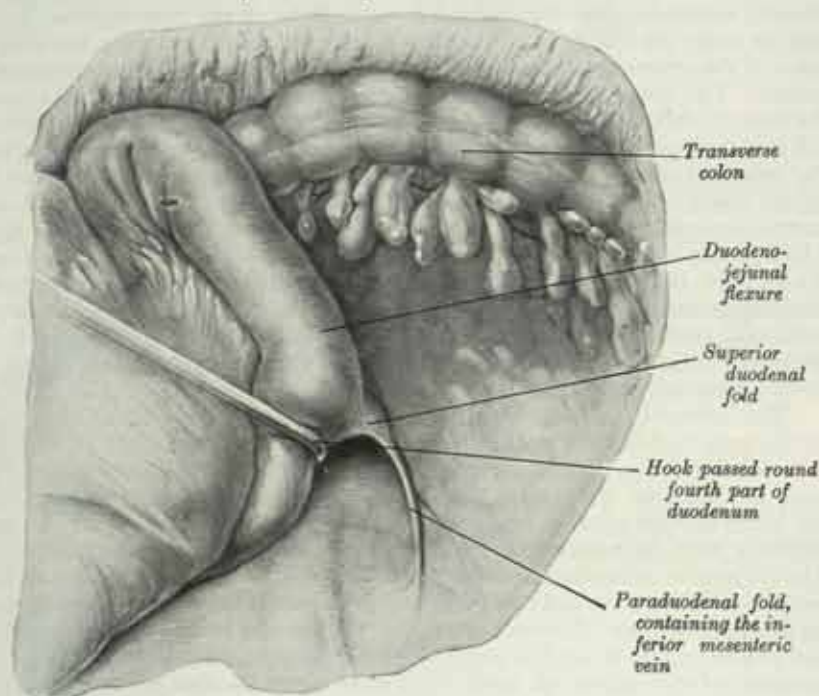
Numerous peritoneal folds extend between the various organs or connect them to the parietes; they serve to enclose the vessels and nerves proceeding to the viscera and, although they are clearly not designed to sustain any weight, they help to retain certain of the viscera in contact with one another. They are grouped as ligaments, omenta and mesenteries.

The **ligaments** will be described with their respective organs.

There are two **omenta**, the lesser and the greater.

The *lesser omentum* is the fold of peritoneum which extends to the liver from the lesser curvature of the stomach and the commencement of the duodenum. It is continuous with the two layers which cover the antero-superior and postero-inferior surfaces of the stomach and the first 2 cm., or less, of the duodenum. From the lower part of the lesser curvature of the stomach and the upper border of the duodenum, these two layers ascend as a double fold to the porta hepatis; from the upper part of the lesser curvature, the two layers pass to be attached to the bottom of the fissure for the ligamentum venosum. The hepatic attachment of the lesser omentum is, therefore, J-shaped, the horizontal limb corresponding to the margins of the porta hepatis, and the vertical limb to the floor of the fissure for the ligamentum venosum. At the upper end of the latter, the lesser omentum reaches the Diaphragm, where the two layers separate to embrace the end of the œsophagus. At the right border of the omentum the two layers are continuous, and form a free margin which constitutes the anterior boundary of the epiploic foramen. The

FIG. 1171.—The superior duodenal recess.



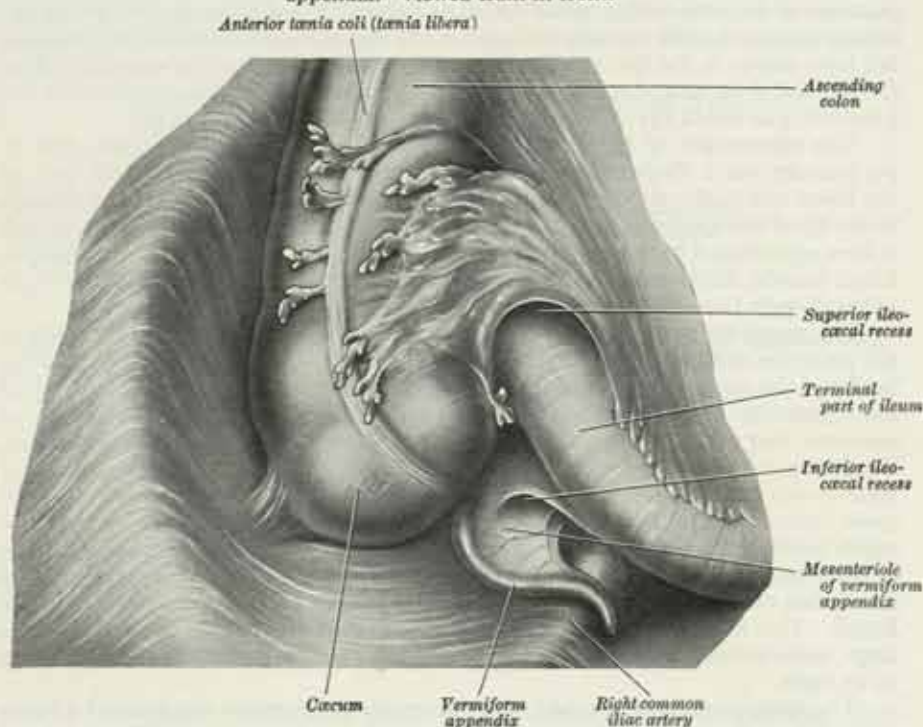
portion of the lesser omentum extending between the liver and stomach is named the *hepatogastric ligament*, and that between the liver and duodenum the *hepato-duodenal ligament*. Close to its right free margin the two layers of the lesser omentum enclose the hepatic artery, portal vein and bile duct, a few lymph nodes and lymph vessels, and the hepatic plexus of nerves—all these structures being enclosed in a fibrous capsule, termed the *perivascular fibrous capsule*. The right and left gastric arteries, the corresponding veins, filaments from the gastric (vagus) nerves (p. 1422), and some of the left gastric lymph nodes and their vessels, lie between the layers of the lesser omentum, where these are attached to the stomach. The left part of the lesser omentum is thinner than the right part and may be fenestrated.

The *greater omentum* is the largest peritoneal fold. It consists of a double sheet, folded on itself so that it is made up of four layers. The two layers which descend from the stomach and commencement of the duodenum pass downwards in front of the small intestine for a variable distance; they then turn upon themselves, and ascend again as far as the anterosuperior aspect of the transverse colon (opposite the *tænia omentalis*). They fuse with, but are separable from, the peritoneum on the upper surface of the transverse colon and the upper layer of the transverse mesocolon (see pp. 1402, 1406). The left border of the greater omentum is continuous

above with the gastrosplenic ligament; its right border extends as far as the commencement of the duodenum. The greater omentum is usually thin, and presents a cribriform appearance, but it always contains some adipose tissue, which in fat people is present in considerable quantity. Between its anterior two layers, about a finger's breadth from the greater curvature of the stomach, the right and left gastro-epiploic vessels anastomose with each other.

Apart from functioning as a storehouse for fat, the greater omentum to some extent acts as a 'protector' against the spread of infection from the viscera into the peritoneal cavity. In this connection it is noteworthy that, when the abdomen is carefully opened without disturbing the organs, the greater omentum is frequently found tucked up about the organs in the upper part of the abdomen; only occasionally is it found spread out evenly in front of the intestines. It has a lesser capacity for absorption than the peritoneum in general and this factor, coupled with its mobility,

FIG. 1172.—The terminal part of the ileum, the cæcum and the vermiform appendix. Viewed from in front.



is important in the protective role it plays in inflammation of the viscera. That it is not a vital physiological organ is indicated by the facts that it is occasionally congenitally absent and that it may be removed without apparent ill effect. The greater omentum contains numerous fixed macrophages (histiocytes, p. 12), which can be mobilised into free macrophages. These cells may accumulate in places into dense, oval or round patches, visible to the naked eye as 'milky spots' on the omentum. Similar spots may be found on other serous membranes (pleura, pericardium).

The **mesenteries** are: the mesentery (mesentery proper), the mesenteriole of the vermiform appendix, the transverse mesocolon and the sigmoid mesocolon. In addition to these an ascending and a descending mesocolon are sometimes present.

The **mesentery** is a broad, fan-shaped fold of peritoneum connecting the coils of jejunum and ileum to the posterior abdominal wall. The border attached to the posterior wall of the abdomen is called the **root of the mesentery**; it is about 15 cm. long and is directed obliquely downwards and to the right from the duodeno-jejunal flexure (at the left side of the second lumbar vertebra) to the upper part of the right sacro-iliac joint. In this course it passes successively in front of the third part of the duodenum (where the superior mesenteric vessels enter the mesentery), the abdominal aorta, the inferior vena cava and the right ureter and right Psoas major muscle. The intestinal border of the mesentery is about 6 metres long and is

thrown into numerous pleats or frills. The pleating diminishes towards the posterior abdominal wall where the root is attached along almost a straight line. The central part of the mesentery is the longest (measured from its root to its intestinal border) and attains a maximum of about 20 cm.; it becomes shorter towards each end. The mesentery consists of two layers of the peritoneum of the greater sac—right and left—between which lie the jejunal and ileal branches of the superior mesenteric artery, with their accompanying veins, nerve plexuses and lymph vessels (here called *lacteals*), the mesenteric lymph nodes, connective tissue and fat. The fat is most abundant in the lower part of the mesentery and here extends from the root to the intestinal border; in the upper part, the mesentery contains less fat and this tends to accumulate near the root and leave oval or circular fat-free, translucent areas ('windows') in the mesentery adjoining the upper part of the jejunum. At the intestinal border of the mesentery, the two layers of peritoneum enclose the gut, forming its visceral peritoneal coat. At the root of the mesentery, the right layer of the peritoneum is reflected, in its lower part, over the posterior abdominal wall to cover the ascending colon, and in its upper part, to become continuous with the inferior layer of the transverse mesocolon; whereas the left layer passes to the left over the posterior abdominal wall and descending colon. (It is helpful to bear this arrangement in mind when determining which is the proximal and which the distal part of a coil of small intestine *in situ*.)

The *mesenteriole of the vermiform appendix* (fig. 1173) is a triangular fold of peritoneum which clothes the vermiform appendix, and is attached to the back of the lower end of the mesentery, close to the ileocaecal junction. It usually extends to the tip of the appendix, but sometimes it fails to reach the distal third, or so, and is here represented by a low peritoneal ridge containing fat. Its layers enclose the blood-vessels, nerves and lymph vessels of the vermiform appendix, together with a lymph node (*see also* p. 1435).

The *transverse mesocolon* is a broad fold which connects the transverse colon to the posterior abdominal wall. Its two layers pass from the anterior surface of the head and the anterior border of the body of the pancreas to the posterior surface of the transverse colon (opposite the *tænia mesocolica*), where they separate to surround that part of the gut. The upper layer is adherent to, but separable from, the greater omentum (*see* pp. 1402, 1406 and fig. 1166). Posteriorly, the upper layer covers the anterior surface of the pancreas and is continuous above with the lower layer of the greater omentum, while the lower layer of the transverse mesocolon covers the inferior surface of the pancreas and passes thence on to the front of the third and fourth parts of the duodenum. Between the layers of the transverse mesocolon the blood-vessels, nerves and lymphatics of the transverse colon are found. The middle colic artery passes downwards and to the right, leaving a large non-vascular area of the fold to its left, and a similar but smaller area to its right.

The *sigmoid mesocolon* is a fold of peritoneum which attaches the sigmoid colon to the pelvic wall. Its line of attachment has the form of an inverted V, the apex of which is near the point of division of the left common iliac artery (fig. 1167); the left limb descends on the medial side of the Psoas major; the right limb passes into the pelvis and ends in the median plane at the level of the third sacral vertebra. The sigmoid and superior rectal vessels run between the two layers of the sigmoid mesocolon and the left ureter runs down into the pelvis behind the apex of its parietal attachment.

In most cases the peritoneum covers only the front and sides of the ascending and descending parts of the colon, but sometimes these are surrounded by peritoneum and attached to the posterior abdominal wall by an ascending and a descending mesocolon respectively (p. 1436). A fold of peritoneum, termed the *phrenicocolic ligament*, is continued from the left colic flexure to the Diaphragm opposite the tenth and eleventh ribs; it has an anterior free border and passes below and lateral to the lateral end of the spleen; it is sometimes given the misleading name of *sustentaculum lienis*.

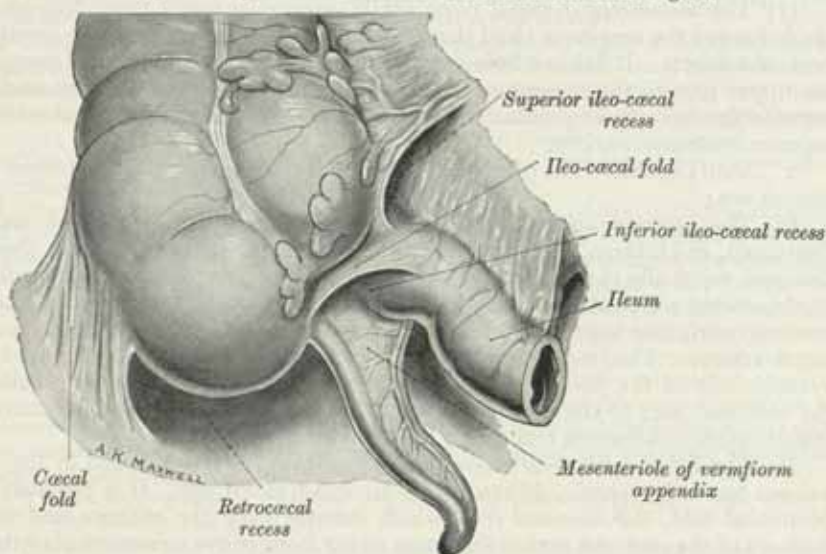
The *appendices epiploicae* are small pouches of the peritoneum filled with fat and situated along the colon; they are best marked on the transverse and sigmoid parts of the colon, absent on the rectum and rudimentary on the caecum and appendix. Many contain a small arteriole which enters them from the wall of the gut. In the case of the colon, they are most numerous along the line of the *tænia libera* (p. 1447).

Peritoneal recesses.—In certain parts of the abdomen, peritoneal folds may sometimes be found which bound fossæ or recesses of the peritoneal cavity. These recesses are of surgical importance since they may become the site of 'internal' herniæ, that is, a piece of intestine may enter a recess and may be constricted (strangulated) by the peritoneal fold guarding the entrance to the recess. As the entrance to the recess must be cut to relieve the strangulation and allow the gut to be drawn out of the recess, it is necessary to note whether the fold contains a blood-vessel or is avascular. From a surgical point of view the omental bursa can be considered to belong to this category, with its opening at the epiploic foramen, guarded in front by the free border of the lesser omentum. Other recesses, of much smaller size, are sometimes found in relation to the duodenum, cæcum and sigmoid mesocolon.

1. *Duodenal recesses:*

(a) The *superior duodenal recess* (fig. 1165) is present in about 50 per cent. of subjects; it may exist alone but usually occurs together with the inferior duodenal recess. It lies on the left side of the upper portion of the fourth part of the duodenum, opposite the second lumbar vertebra, and is situated behind a sickle-shaped

FIG. 1173.—The peritoneal folds and recesses in the cæcal region.



fold of peritoneum, the *superior duodenal fold*, which has a semilunar free lower margin and which merges, on the left, with the peritoneum covering the front of the left kidney. The inferior mesenteric vein lies behind the point of junction between the left end of the superior duodenal fold and the posterior parietal peritoneum. The recess is about 2 cm. deep and admits a fingertip; its orifice looks downwards and is situated in the angle formed by the left renal vein as it crosses in front of the abdominal aorta.

(b) The *inferior duodenal recess* (fig. 1165) is present in about 75 per cent. of subjects, usually in association with a superior duodenal recess, with which it may share a single oval orifice. It lies on the left side of the lower portion of the fourth part of the duodenum, opposite the third lumbar vertebra, and is situated behind a non-vascular, triangular peritoneal fold, the *inferior duodenal fold*, which has a sharp upper free margin. The recess is about 3 cm. deep and admits the tips of one or two fingers; its orifice looks upwards, facing that of the superior duodenal recess. According to Rendle Short (*Brit. J. Surg.*, 1925, vol. 12, p. 456), the superior and inferior duodenal fossæ do not appear to be of pathological importance. The inferior duodenal recess, however, may sometimes extend behind the fourth part of the duodenum and to the left in front of the ascending branch of the left colic artery and the inferior mesenteric vein; in these circumstances this large fossa is liable to become the site of an internal hernia.

(c) The *paraduodenal recess* (fig. 1171) may occur together with the superior and

inferior duodenal recesses. It is found more frequently in the foetus and the new-born child than in the adult, in whom it occurs in about 2 per cent. of subjects. It lies a little to the left of the fourth part of the duodenum, behind a falciform peritoneal fold (paraduodenal fold), the right free edge of which contains the inferior mesenteric vein accompanied by the ascending branch of the left colic artery, the fold forming a mesentery for these vessels. The free margin of the fold lies in front of the wide orifice of the recess, which is directed towards the right.

(d) The *retroduodenal recess* is only occasionally present. It is the largest of the duodenal recesses and lies behind the third and fourth parts of the duodenum, in front of the abdominal aorta. It extends upwards nearly as far as the duodenojejunal junction, being about 8 to 10 cm. deep, and is bounded on either side by peritoneal folds (the duodenoparietal folds); its orifice looks downwards and to the left.

(e) The *duodenojejunal* or *mesocolic recess* is present in about 20 per cent. of subjects and is rarely or never accompanied by any other variety of duodenal recess. It is about 3 cm. deep and lies on the left side of the abdominal aorta, between the duodenojejunal junction and the root of the transverse mesocolon; it is bounded above by the pancreas, on the left by the left kidney, and below by the left renal vein. Its orifice is circular, bounded by two peritoneal folds (duodenomesocolic folds), and looks downwards and to the right.

(f) The *mesenterico-parietal recess* (of Waldeyer) is found more frequently in the foetus and the new-born child than in the adult, in whom it occurs in about 1 per cent. of subjects. It lies just below the third part of the duodenum and invaginates the upper part of the mesentery towards the right. Its orifice is large and looks towards the left; it is guarded in front by a fold of the mesentery raised by the superior mesenteric artery.

2. *Cæcal recesses*.—The principal peritoneal recesses in the neighbourhood of the cæcum are:

(a) The *superior ileocæcal recess* (figs. 1172, 1173) is usually present, and best developed, in children, but it may become reduced in size and is often absent in the aged, especially in the obese. It is formed by a peritoneal fold (the *vascular fold of the cæcum*) which arches over the branch of the ileocolic artery (and its accompanying vein) that supplies the ileocæcal junction on its anterior surface (anterior cæcal artery). The recess is a narrow chink and is bounded, in front, by the vascular fold of the cæcum; behind, by the mesentery of the ileum; below, by the terminal part of the ileum and, on the right, by the ileocæcal junction. Its orifice opens downwards and to the left.

(b) The *inferior ileocæcal recess* (figs. 1172, 1173) is well-marked in the young subject but is frequently obliterated by fat in advanced age. It is produced by a peritoneal fold, the *ileocæcal fold*, which extends from the anterior and inferior surfaces of the terminal part of the ileum to the front of the mesenteriole of the vermiform appendix (or to the appendix or the cæcum). The ileocæcal fold is also known as the 'bloodless fold of Treves', but it sometimes contains blood-vessels; if inflamed, and especially if the appendix and its mesenteriole lie behind the cæcum, the fold may be mistaken for the mesenteriole of the appendix. The inferior ileocæcal recess is bounded, in front, by the ileocæcal fold; above, by the posterior surface of the ileum and its mesentery; to the right by the cæcum, and, behind, by the upper part of the mesenteriole of the vermiform appendix. Its orifice opens towards the left and downwards.

(c) The *retrocæcal recess* (fig. 1173) lies behind the cæcum; it varies much in size and extent and may occasionally extend upwards for some distance behind the ascending colon and be deep enough to admit an entire finger. It is bounded, in front, by the cæcum (and sometimes the lower part of the ascending colon); behind, by the parietal peritoneum and, on each side, by the *cæcal folds* (parietocolic folds) of peritoneum passing from the cæcum to the posterior abdominal wall. The vermiform appendix frequently lies in this recess (p. 1435).

3. The *intersigmoid recess* is constantly present in the foetus and during infancy, but may disappear as age advances. It lies behind the apex of the A-shaped parietal attachment of the root of the sigmoid mesocolon and forms a funnel-shaped recess which is directed upwards; its orifice opens downwards. The recess varies in size from a mere dimple to a fossa which will admit the little finger, and its posterior wall, formed by the peritoneum on the posterior abdominal wall, covers the left ureter as it crosses the bifurcation of the left common iliac artery. Occasionally the

recess lies within the layers of the sigmoid mesocolon nearer the gut than the root of the mesocolon. The presence of the recess is due to imperfect blending of the mesocolon with the posterior parietal peritoneum.

Anomalous peritoneal folds.—In addition to the folds described above in connexion with the peritoneal recesses, certain other peritoneal folds, bands, or ligaments are sometimes found in the abdomen. They are of interest in that some of them are considered to cause obstruction to the passage of food materials along the gut by exerting traction on, and producing angulation of sections of the intestine. Others are thought to be of importance in limiting the spread of peritoneal effusions to certain localities in the abdomen. Their exact mode of origin is doubtful and they have been variously attributed to errors in development, to previous inflammation (peritonitis) and to mechanical traction by the gut, possibly associated with the evolution of the upright posture in man, though the latter factor is improbable. These anatomically anomalous folds must be distinguished from pathological adhesions which are definitely due to peritonitis, and it must be borne in mind that, when coils of intestine are pulled out of their normal position by the observer, they may be artificially kinked by the traction thus exerted upon their mesenteries, with resultant simulation of bands, whereas none actually existed with the gut *in situ*. Further, these anomalous folds only become of clinical importance if it be proved, in a given case, that they interfere with the normal function of the gut, and mere discovery of their presence should not cause a search for another—the real—cause of the symptoms to be neglected. The principal anomalous folds which are encountered are as follows :

(a) Occasionally the lesser omentum is prolonged to the right of the usual site of the epiploic foramen in the form of a peritoneal fold which may pass from the gall-bladder to the first part of the duodenum (cystoduodenal ligament), or in front of the latter to the greater omentum or right colic flexure ; or from the under surface of the right lobe of the liver to the right colic flexure (hepatocolic ligament).

(b) The duodenojejunal junction is sometimes joined to the transverse mesocolon by a peritoneal band.

(c) The greater omentum may be attached to the front of the ascending colon or extend over it to the lateral abdominal wall. A thin sheet of peritoneum (Jackson's membrane), containing fine blood-vessels, may pass from the front of the ascending colon and cæcum to the lateral part of the posterior abdominal wall ; it may be continuous, on the left, with the greater omentum. Occasionally a peritoneal band passes from the right side of the ascending colon to the lateral abdominal wall at about the level of the iliac crest ; it has been called the 'sustentaculum hepatis', but it is only closely related to the liver in foetal and early postnatal life, when that organ is relatively larger than in the adult. Other folds passing from the ascending colon to the posterolateral abdominal wall may divide the right lateral paracolic gutter (the groove between the right side of the ascending colon and the posterior abdominal wall) into several small recesses.

(d) The ascending colon, and less frequently the descending colon, may have a mesentery (see footnote on p. 1435).

(e) The proximal and distal ends of the sigmoid colon may be bound close to each other by a fibrous band.

(f) Frequently a fan-shaped peritoneal fold [the presplenic fold] extends from the anterior surface of the gastrosplenic ligament (near the greater curvature of the stomach), below the lateral end of the spleen, to blend with the phrenicocolic ligament. It may be adherent to the spleen or to the Diaphragm, and it contains branches from the splenic or left gastro-epiploic artery. The omental bursa may be prolonged into the fold. The fold is better marked in the fœtus than in the adult, in whom it often appears to be merely a part of the phrenicocolic ligament. It may be of importance in limiting peritoneal effusions in the left subphrenic region (see below), and, if adherent to the spleen or Diaphragm, it may form a vascular obstruction in the surgical removal of the spleen.

(g) A fibrous band, described as passing from the terminal part of the ileum to the posterior abdominal wall, and a similar one passing from the proximal part of the sigmoid colon to the posterior abdominal wall, were formerly thought to be the cause of partial obstruction by producing kinking of these parts of the gut, but such a view does not receive much support at the present time.

Special regions of the peritoneal cavity.—From the point of view of the spread of pathological collections of fluid, the peritoneal cavity is subdivided into a number of potential spaces which are normally in communication with each other, but which may become sealed off from one another by pathological adhesions between the neighbouring peritoneum and viscera. These spaces are as follows :

(1) The *supracolic space* (or subphrenic region) lies between the Diaphragm above, and the transverse colon and its mesocolon below. It is subdivided into (a) the *right subphrenic space*, which lies between the Diaphragm and the anterior, superior and right lateral surfaces of the right lobe of the liver, bounded to the left by the falciform liga-

ment, and behind by the upper layer of the coronary ligament; (b) the *left subphrenic space*, which lies between the Diaphragm, the anterior and superior surfaces of the left lobe of the liver, the anterosuperior surface of the stomach, and the diaphragmatic surface of the spleen, bounded to the right by the falciform ligament, and behind by the anterior layer of the left triangular ligament; (c) the *right subhepatic space* (also known as the hepatorenal pouch, and Morison's pouch), which is bounded, above and in front, by the inferior surface of the right lobe of the liver and by the gall-bladder; below and behind, by the right suprarenal gland, the upper part of the right kidney, the second part of the duodenum, the right colic flexure, the transverse mesocolon and part of the head of the pancreas; above and behind, it extends between the right kidney and liver as far as the inferior layer of the coronary ligament and the right triangular ligament; (d) the *left subhepatic space*, which is the omental bursa.

(2) The *right infracolic space* lies below and behind the transverse colon and mesocolon and to the right side of the mesentery, owing to the obliquity of which the space is widest above. The vermiform appendix sometimes lies in the lower part of this space.

(3) The *left infracolic space* lies below and behind the transverse colon and mesocolon and to the left of the mesentery; it is widest below and in free communication with the pelvis.

(4) The *pelvic cavity*.

Two extraperitoneal 'spaces' in the subphrenic region are defined, which may likewise become the site of localised infection. They are: (a) the *right extraperitoneal space*, which lies between the two layers of the coronary ligament, the 'bare area' of the liver, and the Diaphragm; and (b) the *left extraperitoneal space*, which comprises the extraperitoneal connective tissue around the left suprarenal gland and the upper pole of the left kidney.

Absorption from the peritoneal cavity.—With regard to the question of the absorption of fluid effusions from the peritoneal cavity, substances in complete solution (solutes) are probably absorbed directly into the blood capillaries, whereas particulate matter in suspension probably passes into the lymph vessels, with the aid of phagocytes (polymorphonuclears and monocytes). After abdominal or pelvic operations, it has been customary to prop up the patient in bed so that any inflammatory intraperitoneal effusion that may ensue will gravitate into the pelvis. The presumed reason for adopting this position was that the peritoneum in the subphrenic region had a greater absorptive capacity than the other regions; hence the inflammatory material, if it gained access to this region, would more rapidly pass into the general circulation. It was held by some that in the subphrenic region there were gaps (peritoneal stomata) between the epithelial cells lining the peritoneum and similar gaps (endothelial stigmata) between the endothelial cells lining the lymph vessels subjacent to the peritoneum, and that these gaps greatly facilitated absorption. It is now generally believed that these gaps are artefacts produced during the histological technique employed to demonstrate them, that absorption is more or less equally rapid in all parts of the peritoneum, and that the greater absorption in the upper part of the abdomen is to be correlated partly with the larger area of the peritoneal surface in the subphrenic region and partly with the fact that respiratory movements expedite absorption in this zone.

Vessels and nerves of the peritoneum.—The parietal and visceral layers of the peritoneum are respectively developed from the somatopleural and splanchnopleural layers of the lateral plate mesoderm (p. 77). Correlated with their embryological origin, it is found that the parietal peritoneum derives its arterial supply from the somatic (body-wall) arteries supplying the abdominal and pelvic walls, its veins join the systemic veins in the neighbouring parts of the body-wall, its lymphatics also join those in the body-wall and thus drain into parietal lymph nodes, and its nerve-supply is derived from the spinal nerves supplying the muscles and skin of the body-wall; whereas the visceral peritoneum, which is to be considered as an integral part of the viscera themselves, derives its arterial supply from the arteries supplying the appropriate viscera, its veins and lymphatics join the visceral veins and lymph vessels, and its nerve-supply is derived from the sympathetic nerves innervating the viscera. The differences in the sensibility of the two layers of the peritoneum is thus to be correlated with their different innervation. Whereas pain is elicited by the application of tactile, thermal or chemical impulses to the parietal peritoneum (in the conscious patient), these stimuli do not form adequate stimuli when applied to the visceral peritoneum (or to the viscera themselves). For example, the liver, stomach or intestine can be cut, pinched, clamped or burned in the conscious subject without evoking pain, the insensibility of the alimentary canal to these forms of stimulation extending from about the middle of the œsophagus down to the junction of the entodermal and ectodermal parts of the anal canal. On the other hand, an adequate stimulus which provokes pain in the viscera or visceral peritoneum is tension, such as may be produced by over-distension of the hollow viscera or traction on the mesen-

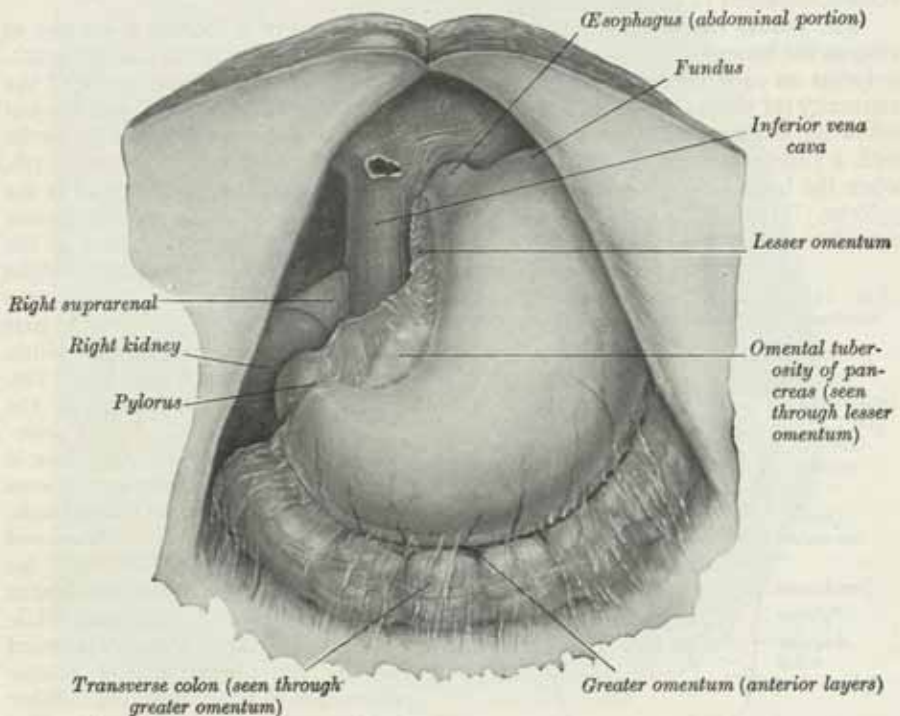
teries, which stretches the nerve plexuses in the walls of the organs or the nerves in the mesenteries. Other adequate stimuli are spasm of visceral muscle, and ischaemia (deprivation of blood supply). The somatic nerves which supply the parietal peritoneum also supply the neighbouring (or corresponding segmental area of) skin and the trunk muscles, and in cases where the parietal peritoneum is irritated (for example, by inflammation) the muscles are reflexly stimulated to contract, thus producing rigidity of the abdominal wall in that region.

THE STOMACH [VENTRICULUS]

The **stomach** is the most dilated part of the digestive tube, and is situated between the end of the œsophagus and the beginning of the small intestine. It lies in the epigastric, umbilical, and left hypochondriac regions of the abdomen, and occupies a recess bounded by the upper abdominal viscera, and completed in front and on the left side by the anterior abdominal wall and the Diaphragm.

The *shape* and *position* of the stomach are so greatly modified by changes within itself and in the surrounding viscera that no one form and no single position can be

FIG. 1174.—The stomach *in situ*, after the removal of the liver.



described as typical. The chief modifications are determined by (1) the amount of the stomach contents, (2) the stage which the digestive process has reached, (3) the degree of development of the gastric musculature, and (4) the condition of the adjacent intestines; but certain features are more or less common to all (*see also* p. 1418).

The stomach has two openings, two borders or curvatures, and two surfaces.

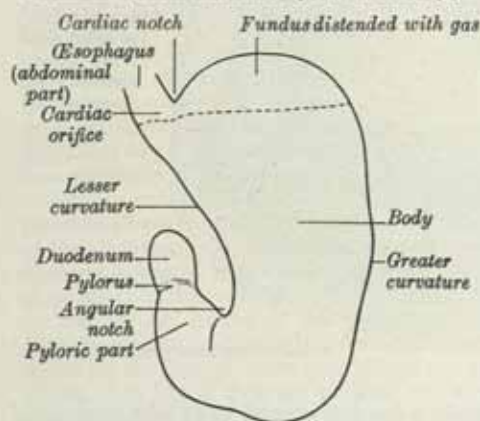
Openings.—The opening by which the œsophagus communicates with the stomach is known as the *cardiac orifice*, and is situated on the left of the median plane, behind the seventh costal cartilage 2.5 cm. (one inch) from its junction with the sternum, and at the level of the eleventh thoracic vertebra. It is placed about 10 cm. from the anterior abdominal wall and is 40 cm. (16 inches) from the incisor teeth. The short abdominal portion of the œsophagus is conical in shape and curved sharply to the left, the base of the cone being continuous with the cardiac orifice of the stomach. The right margin of the œsophagus is continuous with the lesser curvature of the stomach, while the left margin joins the greater curvature at an acute angle, termed the *cardiac notch*. The part of the stomach which lies to the left of and above the level of the cardiac orifice is called the *fundus*.

The opening by which the stomach communicates with the duodenum is named the *pyloric orifice*, and its position is usually indicated (fig. 1174) by a circular groove on the surface of the organ, termed the *pyloric constriction*, which indicates the position of the pyloric sphincter. In the living subject, at operation, it can be identified by the prepyloric vein, which runs vertically across its anterior surface. The pyloric orifice lies 1.2 cm. (half an inch) to the right of the median plane at the level of the lower border of the first lumbar vertebra, *when the body is in the supine position and the stomach is empty*.

Curvatures.—The *lesser curvature*, extending between the cardiac and pyloric orifices, forms the right or posterior border of the stomach. It descends as a continuation of the right margin of the œsophagus in front of the decussating fibres of the right crus of the Diaphragm, and then, turning to the right, it curves below the omental tuberosity of the pancreas and ends at the pylorus (fig. 1174). The most dependent part of the curve forms a notch, named the *angular notch*, which varies somewhat in position with the state of distension of the viscus; it serves to separate the stomach into a right and a left portion. The lesser curvature gives attachment to the lesser omentum, the two layers of which contain the right and left gastric vessels, adjacent to the lesser curvature.

The *greater curvature* is directed mainly forwards, and is four or five times as long as the lesser curvature. Starting from the cardiac orifice at the cardiac notch, it forms an arch backwards, upwards, and to the left; the highest point of the convexity (of the *fundus*) is on a level with the left fifth intercostal space and lies just below the left nipple. From this level it may be followed downwards and forwards, with a slight convexity to the left almost as low as the cartilage of the tenth rib, when the body is in the supine position; it then turns to the right, to end at the pylorus. Directly opposite the angular notch of the lesser curvature the greater curvature presents a bulge, which is the left extremity of the *pyloric part* of the

FIG. 1175.—An outline of the normal full stomach. (From a model by A. E. Barclay.)



stomach; this is limited on the right by a slight groove, which indicates the subdivision of the pyloric part into a pyloric antrum and a pyloric canal. The latter is only 2 to 3 cm. in length and terminates at the pyloric constriction. At its commencement the greater curvature is covered by peritoneum continuous with that on the front of the stomach. On the left side of the fundus and the adjoining part of the body, the greater curvature gives attachment to the gastrosplenic ligament, while its lower portion gives attachment to the two layers of the greater omentum, separated from each other by the gastro-epiploic vessels. The gastrosplenic ligament and the greater omentum are directly continuous, as

they are both parts of the original dorsal mesentery of the stomach (dorsal mesogastrium) (p. 197).

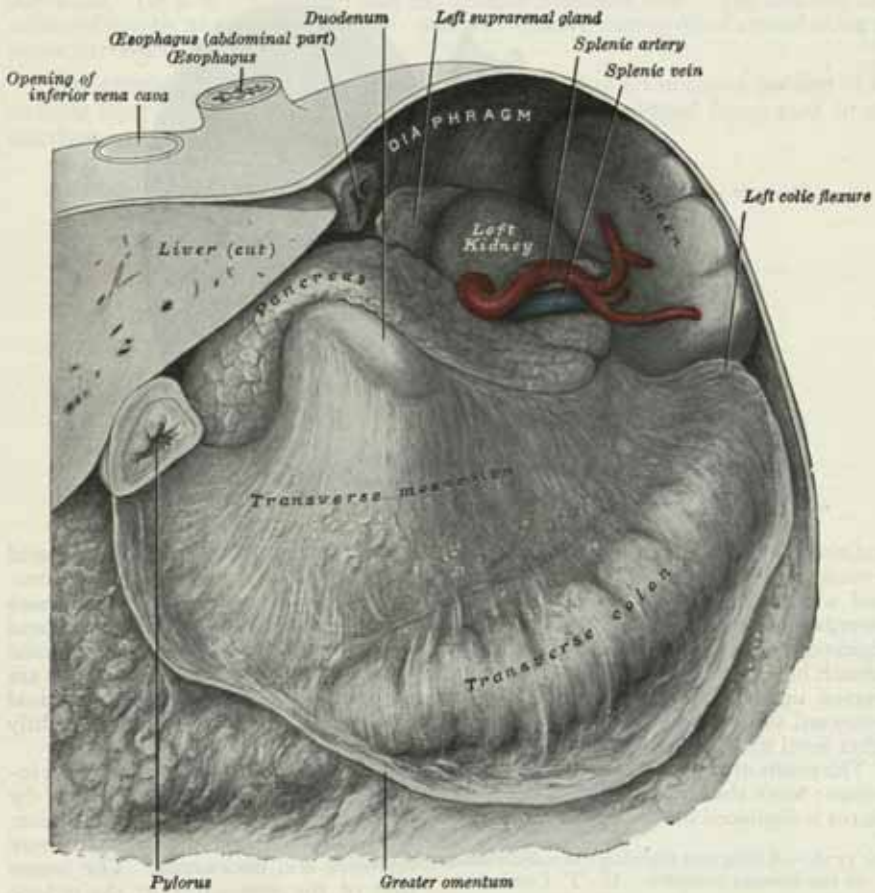
Surfaces.—When the stomach is empty and its walls contracted, its surfaces are directed upwards and downwards respectively, but when it is distended they look forwards and backwards. They may therefore be described as anterosuperior and postero-inferior.

Anterosuperior surface.—The left part of this surface lies under cover of the left costal margin. It is in contact with the Diaphragm, which separates it from the left pleura, the base of the left lung, the pericardium, and the sixth, seventh, eighth and ninth ribs and intercostal spaces of the left side. It is also in relation to the upper fibres of origin of the Transversus abdominis, which intervene between it and the seventh, eighth and ninth costal cartilages. The upper and left part of this surface becomes posterolateral and is in contact with the gastric surface of the spleen. The right half is in relation with the left and quadrate lobes of the liver and with the anterior abdominal wall. When the stomach is empty, the transverse colon may lie

on the front part of this surface. The whole surface is covered with peritoneum, and a part of the greater sac of the peritoneum intervenes between it and the above structures.

The *postero-inferior surface* is in relation with the Diaphragm, the left suprarenal gland, the upper part of the front of the left kidney, the splenic artery, the anterior surface of the pancreas, the left colic flexure, and the upper layer of the transverse mesocolon. These structures form the shallow *stomach-bed*, on which the viscus rests (fig. 1176), but the stomach is separated from them by the omental bursa. The gastric surface of the spleen is also generally described as part of the stomach-bed, but as stated above it is separated from the stomach by a part of the greater

FIG. 1176.—The 'stomach-bed'.



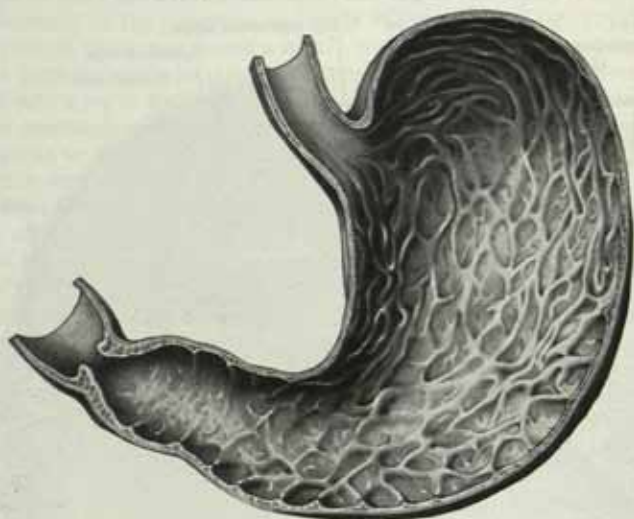
sac. Further, the greater omentum and the transverse mesocolon separate the stomach from the duodenojejunal flexure and small intestine. The postero-inferior surface is covered with peritoneum, except near the cardiac orifice, where there is a small, somewhat triangular area, in direct contact with the left crus of the Diaphragm, and sometimes with the left suprarenal gland. The left gastric vessels reach the lesser curvature of the stomach at the right extremity of this area (in the left gastropancreatic fold, p. 1407), and from its left side a short peritoneal fold, termed the *gastrophrenic ligament*, which is continuous below with the lienorenal and gastrosplenic ligaments, passes to the inferior surface of the Diaphragm.

A plane passing through the angular notch on the lesser curvature and the left limit of the opposed bulge on the greater curvature divides the stomach into a large, left portion or *body* and a small, right, or *pyloric part*.

By means of X-rays the form and position of the stomach can be studied in the living subject after the administration of a meal containing barium sulphate (Pl. XXVI). During the process of digestion, it is divided by a muscular constriction into a large, dilated, left portion, and a narrow, contracted, tubular, right portion.

The constriction is in the body of the stomach, and does not follow any of the anatomical landmarks; indeed, it shifts gradually towards the left as digestion progresses. The position of the stomach varies with the posture, with the amount of the stomach contents and with the condition of the intestines on which it rests. It is also influenced by the tone of the abdominal muscles and of the musculature of the organ itself, and by the type of body build of the individual. In the commonest type of stomach, the empty organ is somewhat J-shaped and, in the erect posture the pylorus descends to the level of the second or the upper part of the third lumbar vertebra, and the most dependent part of the stomach is below the level of the umbilicus. The fundus is usually distended with gas. Variation in the amount of its contents affects mainly the body of the stomach, the pyloric portion remaining in a more or less contracted

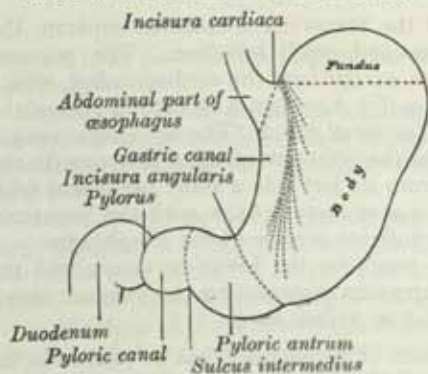
FIG. 1177.—The interior of the stomach.



condition during the process of digestion. As the stomach fills it tends to expand forwards and downwards in the direction of least resistance, but when this is interfered with by a distended condition of the colon or intestines the fundus presses upwards on the liver and Diaphragm and gives rise to the feelings of oppression and palpitation complained of in such cases. When hardened *in situ* the contracted stomach has a sickle shape, the fundus looking directly backwards. The surfaces are directed upwards and downwards, the upper surface having, however, a gradual downward slope to the right. The greater curvature is in front of and at a slightly higher level than the lesser.

The position of the full stomach depends, as already indicated, on the state of the intestines: when the latter are empty the fundus expands vertically and also forwards, the pylorus is displaced towards the right, and the whole organ assumes an oblique position,

FIG. 1178.—A diagram showing the subdivisions of the human stomach. (F. T. Lewis.)



so that its surfaces are directed more forwards and backwards. The lowest part of the stomach is at the pyloric antrum, which reaches below the umbilicus. Where the intestines interfere with the downward expansion of the fundus the stomach retains the horizontal position which is characteristic of the contracted viscus. Less commonly the stomach may lie almost transversely, even in the erect posture; this is known as the 'steer-horn' type of stomach. Intermediate types of stomach, between the J-shaped and 'steer-horn' varieties also occur.

Interior of the stomach.—When examined after death, the stomach is usually fixed at some stage of the digestive process. A common form is that

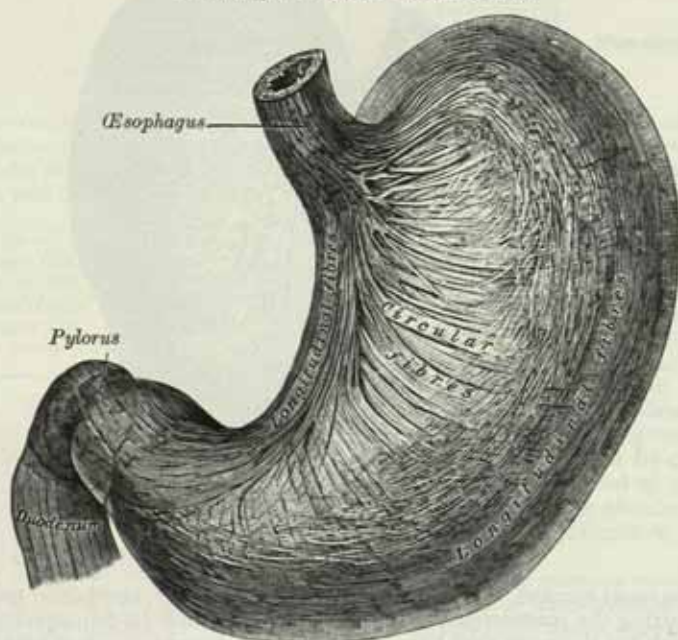
shown in fig. 1177. When the viscus is laid open by a section through the plane of its two curvatures, it is seen to consist of two segments: (a) a large globular portion on

the left and (b) a narrow tubular part on the right. The cardiac notch lies to the left of the abdominal part of the œsophagus: the projection of this notch into the cavity of the stomach increases as the organ distends, and has been supposed to act as a valve preventing regurgitation into the œsophagus. The elevation corresponding to the angular notch is seen at the beginning, and the circular thickening of the pyloric sphincter at the end of the pyloric portion.

F. T. Lewis * has modelled the gastric epithelium in the human embryo, and has shown that a canal (named by him the *gastric canal*) extends along the lesser curvature from the cardiac orifice to the angular notch (fig. 1178), the distinctness of the canal being strikingly shown when the model is viewed from the inside. Jefferson † has brought forward radiographic evidence to show that such a canal exists in the adult. He found that in eighteen out of twenty-two cases examined whilst in the act of swallowing a mixture of oxychloride of bismuth and milk the fluid was confined to the lesser curvature. He is of the opinion that the oblique muscular coat of the stomach is so arranged that by its contraction it will cause a temporary cutting off of a canal along the lesser curvature.

The *pyloric sphincter* is a muscular ring composed of a thickened portion of the circular layer of the muscular coat. Some of the longitudinal fibres turn in and interlace with the fibres of the sphincter.

FIG. 1179.—The longitudinal and circular muscular fibres of the stomach. Anterosuperior aspect. (Spalteholz.)



Structure.—The wall of the stomach consists of four coats: serous, muscular, submucous and mucous, together with vessels and nerves.

The *serous coat*, or visceral peritoneum, covers the entire surface of the organ, excepting (a) along the greater and lesser curvatures at the lines of attachment of the greater and lesser omenta, where the two layers of peritoneum leave a small space in which the vessels and nerves lie: and (b) a small area on the postero-inferior surface of the stomach, close to the cardiac orifice, where the stomach is in contact with the under surface of the Diaphragm at the site of reflection of the gastrophrenic and left gastropancreatic folds.

The *muscular coat* (figs. 1179, 1180) is situated immediately beneath the serous covering, with which it is closely connected. It consists of three layers of unstriated muscular fibres: longitudinal, circular and oblique.

The *longitudinal fibres* are the most superficial, and are arranged in two sets. The first set consists of fibres continuous with the longitudinal fibres of the œsophagus; they radiate from the cardiac orifice and end proximal to the pyloric portion. The second set commences on the body of the stomach and passes to the right, its fibres

* *American Journal of Anatomy*, 13, p. 477, 1912.

† *J. Anat. and Physiol.*, 1915, 49, 165.

becoming more thickly arranged as they approach the pylorus. Some of the more superficial fibres of this set pass on to the duodenum, but the deeper fibres dip inwards and interlace with the fibres of the pyloric sphincter.

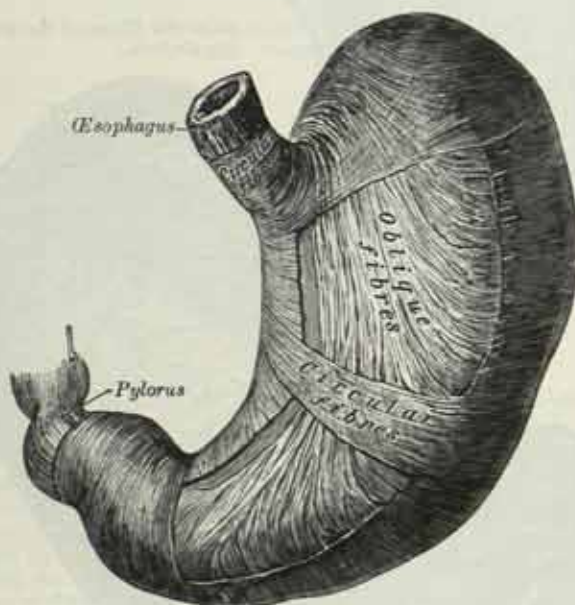
The *circular fibres* form a uniform layer over the whole extent of the stomach beneath the longitudinal fibres. At the pylorus they are most abundant, and are there aggregated into a ring which forms the *pyloric sphincter*. The circular fibres of the stomach are continuous with the circular fibres of the œsophagus, but are sharply marked off from the circular fibres of the duodenum by a connective tissue septum.

The *oblique fibres*, internal to the circular layer, are limited chiefly to the body of the stomach. They sweep downwards from the cardiac notch and run more or less parallel with the lesser curvature. On the right they present a free and well-defined margin (fig. 1180); on the left they blend with the circular fibres.

The *submucous coat* consists of loose, areolar tissue, connecting the mucous and muscular layers.

The *mucous membrane* is thick and its surface is smooth, soft and velvety. In the fresh state it is of a pinkish tinge at the pyloric end, and of a red or reddish-brown colour over the rest of its surface. In infancy it is of a brighter hue, the vascular

FIG. 1180.—The oblique muscular fibres of the stomach.
Anterosuperior aspect. (Spalteholz.)

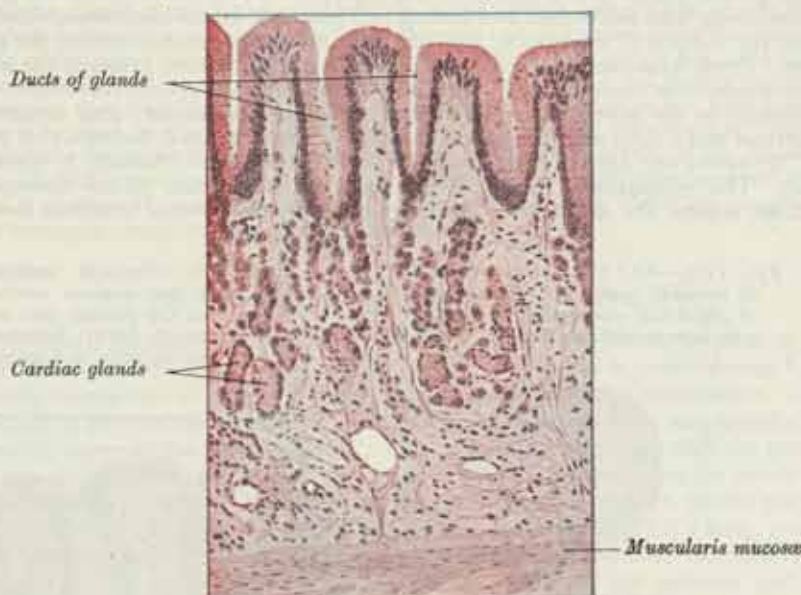


redness being more marked. It is thin at the cardiac extremity, but thicker towards the pylorus. During the contracted state of the organ it is thrown into numerous folds or rugæ which for the most part have a longitudinal direction, and are best marked towards the pyloric end of the stomach, and along the greater curvature (fig. 1177). These folds are obliterated when the organ is distended.

Structure of the mucous membrane.—When examined with a lens, the inner surface of the mucous membrane presents a peculiar, honeycomb appearance owing to the fact that it is dotted with small, shallow depressions or alveoli, of a polygonal or hexagonal form, which vary from 0.12 mm. to 0.25 mm. in diameter. These are the ducts of the gastric glands, and at the bottom of each, one or more of the minute orifices of the gland-tubes may be seen. The surface of the mucous membrane is covered with a single layer of columnar epithelium with occasional goblet-cells. This epithelium commences very abruptly at the cardiac orifice, where there is a sudden transition from the stratified epithelium of the œsophagus. The epithelial lining of the gland-ducts is of the same character and is continuous with the general epithelial lining of the stomach.

The gastric glands are of three kinds: (a) *cardiac*, (b) *fundus* or *oxyntic*, and (c) *pyloric*. The *cardiac glands* (fig. 1181), few in number, occur close to the cardiac orifice. They are of two kinds: (1) simple tubular glands resembling those of the pyloric end of the stomach, but with short ducts; (2) compound racemose glands. The *fundus glands* (fig. 1182, 1183) are found in the body and fundus of the stomach; they are simple tubes, two or more of which open into a single duct. The duct is short,

FIG. 1181.—Vertical section through the mucous membrane of the cardiac part of the stomach (human). Stained with hæmatoxylin and eosin. $\times 6126$.



sometimes not amounting to more than one-sixth of the whole length of the gland. The epithelium of the fundus glands consists of (1) short columnar, glandular cells, known as the *chief* or *central* or *zymogenic cells*, which are responsible for the formation of pepsin, and (2) larger, oval cells, termed *parietal* or *oxyntic cells*, which secrete the hydrochloric acid of the gastric juice. The latter

FIG. 1182.—Vertical section through the mucous membrane of the fundus of the stomach (cat). Stained with hæmatoxylin and eosin. Low power view. $\times 70$.



Note the beaded appearance given by the oxyntic cells.

lie between the chief cells and the basement-membrane, and stain deeply with eosin; they do not form a continuous layer, but occur at intervals and so give the tube a beaded appearance. They are connected with the lumen of the gland by fine channels which run between the central cells. The *pyloric glands* (fig. 1184) are found in the pyloric portion of the stomach. Each consists of two or three short convoluted tubes opening into a funnel-shaped duct. The tubes are lined by cubical cells which are finely granular. Parietal or oxyntic cells are present in some of the pyloric glands. The ducts occupy about two-thirds of the depth of the mucous membrane.

Between the glands the mucous membrane consists of a connective tissue framework, and lymphoid tissue. In places, this latter tissue, especially in early life, is collected into little masses which resemble the solitary follicles of the intestine, and are termed the *gastric lymphatic follicles*. They are not, however, so distinctly circumscribed as the solitary follicles. In the mucous membrane, deep to the glands, is a thin stratum of involuntary muscle fibres, the *muscularis mucosæ*; it consists of an inner circular and an outer longitudinal layer (with a third, outer circular layer, in places). The inner layer sends strands between the glands, the contraction of which probably aids the emptying of the glands.

Vessels and Nerves.—The *arteries* supplying the stomach are: the left gastric branch of the celiac artery, the right gastric and right gastro-epiploic branches of the hepatic artery, and the left gastro-epiploic and short gastric branches of the splenic artery. They supply the muscular coat, ramify in the submucous coat, and are finally distributed to the mucous membrane. The arrangement of the vessels

in the mucous membrane is somewhat peculiar. The arteries break up at the deep ends of the gastric glands into a plexus of fine capillaries which run between the glands, anastomosing with each other, and ending in a plexus of larger capillaries, which surround the mouths of the glands, and also form hexagonal meshes around the gland-ducts. From these the *veins* arise, and pursue a straight course, between the glands, to the submucous tissue: they end either in the splenic and superior mesenteric veins, or directly in the portal vein. The *lymph vessels* are numerous; they consist of a superficial and a deep set; the lymph drainage of the stomach is described on p. 900.

The *nerves* are derived from multiple sources (G. A. G. Mitchell, *J. Anat.*, 75, 1940). The sympathetic supply is mainly from the celiac plexus through the plexuses around the gastric and gastro-epiploic arteries. Some branches from the

FIG. 1183.—(A.) Gland from fundus of stomach (cat); (B.) Lower part of gland cut transversely. Stained with hæmatoxylin and eosin. $\times 530$.



Note.—The peripherally placed cells staining deeply with eosin are the oxyntic cells.

FIG. 1184.—Vertical section through the mucous membrane of the pyloric part of the stomach (cat). Stained with hæmatoxylin and eosin. $\times 676$.



plexus around the hepatic artery reach the lesser curvature by passing between the layers of the hepatogastric ligament (p. 1408). Branches from the left phrenic plexus pass to the cardiac end of the stomach, which also receives a twig from the branch of the left phrenic nerve to the right crus of the diaphragm. Inconstant branches are given to the stomach from the left thoracic splanchnic nerves and from the thoracic and lumbar sympathetic trunks.

The parasympathetic supply is derived from the vagus nerves. Usually one or two nerve-trunks lie on the anterior and one or two on the posterior aspect of the gastro-oesophageal junction; the anterior nerves comprise mainly left vagal fibres, and the posterior right vagal fibres, which have emerged from the oesophageal plexus. The anterior nerves supply several filaments to the cardiac orifice and then divide near the upper end of the lesser curvature into four groups of branches. Of these, (a) gastric branches (4-10) radiate on the anterior surface of the body and fundus of the stomach; one is larger than the others and lies in the lesser omentum near the lesser curvature (the *greater anterior gastric nerve*); and (b) pyloric branches, generally two in number, one running almost horizontally to the right in the lesser omentum towards its free edge and then turning down on the left side of the hepatic artery to reach the pylorus, the other usually arising from the greater anterior gastric nerve

and passing obliquely to the pyloric antrum. The posterior nerves give off two main sets of branches: (a) gastric branches, radiating on the posterior surface of the body and fundus of the stomach; they extend on to the pyloric antrum but do not reach the pyloric sphincter; one of these is larger than the rest and passes along the posterior margin of the lesser curvature (*greater posterior gastric nerve*), giving branches to the celiac plexus; and (b) celiac branches, which are larger than the gastric branches, and pass in the lesser omentum to the celiac plexus. No true plexus formation of nerves is formed on either the anterior or posterior surface of the stomach. Nerve-plexuses are found in the submucous coat and between the layers of the muscular coat. The latter plexus corresponds to the myenteric (*Auerbach's*) plexus of the intestine and contains numerous nerve-cells. From these plexuses fibrils are distributed to the muscular tissue and the mucous membrane.

THE SMALL INTESTINE [INTESTINUM TENUE]

The **small intestine** is a convoluted tube, extending from the pylorus to the ileocaecal valve, where it joins the large intestine. It is about 6.5 metres long,* and gradually diminishes in diameter from its commencement to its termination. It is contained in the central and lower parts of the abdominal cavity and usually lies within the curve of the large intestine; it is in relation, in front, with the greater omentum and abdominal parietes; a portion of it extends down into the pelvis and lies in front of the rectum. The small intestine consists of (1) a short, curved portion which is devoid of a mesentery and is named the *duodenum*, and (2) a long, greatly coiled part which is attached to the posterior abdominal wall by the mesentery (p. 1409), and of which the proximal two-fifths constitute the *jejunum*, and the distal three-fifths the *ileum*.

The **duodenum** (fig. 1185) is so named because its length is about equal to the breadth of twelve fingers (25 cm.). It is the shortest, widest and most fixed part of the small intestine; it has no mesentery, and is only partially covered with peritoneum. Its course presents a remarkably constant curve, somewhat of the shape of an incomplete circle, which encloses the head of the pancreas. It lies entirely above the level of the umbilicus.

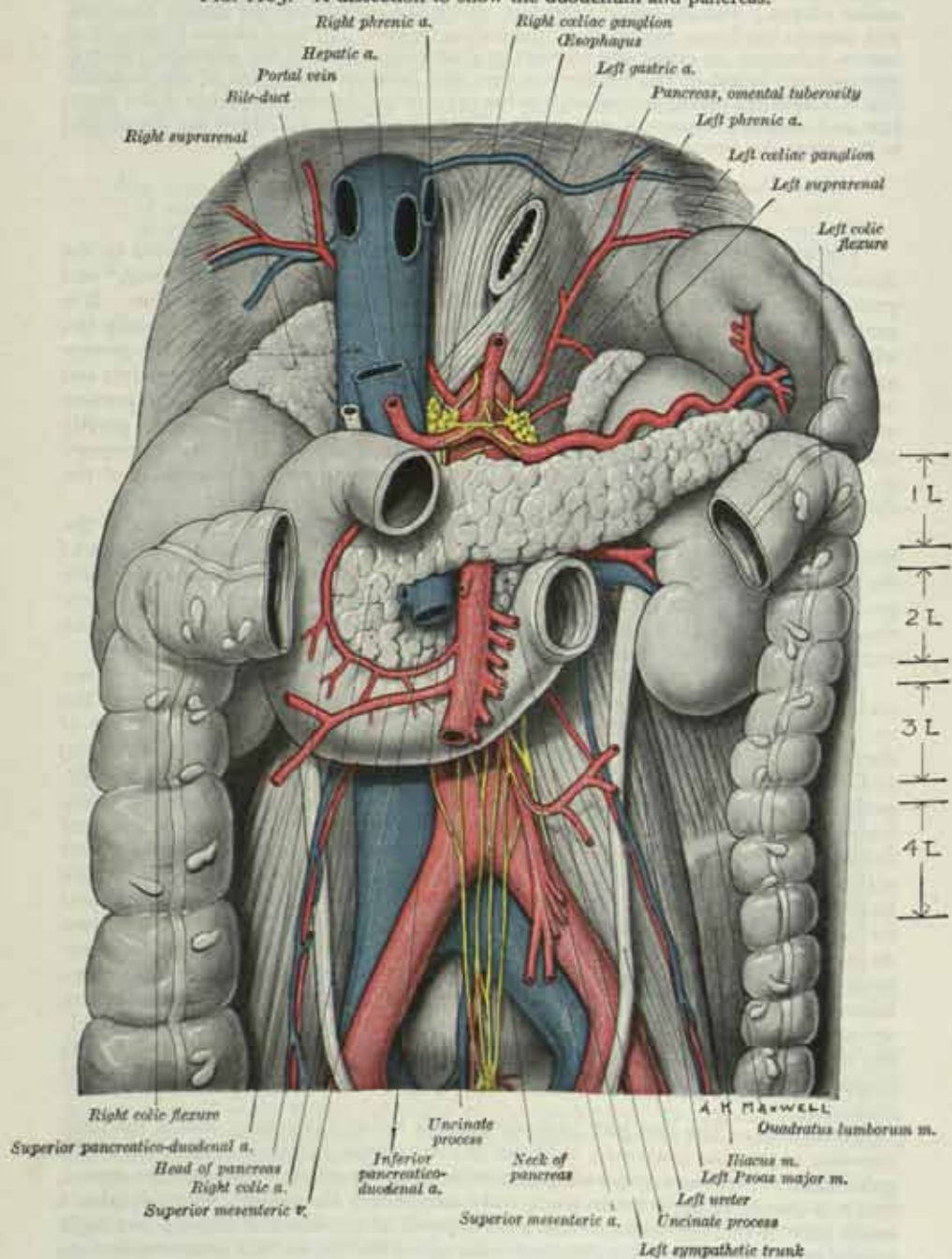
It begins at the pylorus, passes backwards, upwards and to the right for 2.5 cm., under cover of the posterior or upper part of the quadrate lobe of the liver, to the neck of the gall-bladder, varying slightly in direction according to the degree of distention of the stomach; it then makes a sharp curve (*superior duodenal flexure*) and descends for about 7.5 cm. in front of the medial part of the right kidney, generally to the level of the lower border of the body of the third lumbar vertebra, lying immediately medial to the lateral plane (fig. 1186). Here it makes a second bend (*inferior duodenal flexure*), and passes almost horizontally from right to left across the vertebral column just above the level of the umbilicus, having a slight inclination upwards; it then ascends in front, or to the left, of the abdominal aorta for about 2.5 cm., and ends opposite the second lumbar vertebra in the jejunum. At its union with the jejunum it turns abruptly forwards, forming the *duodeno-jejunal flexure*, which is situated 2.5 cm. to the left of the median plane and 1 cm. below the transpyloric plane. For descriptive purposes it is divided into first, second, third and fourth parts. The first and second parts are called respectively the superior and descending parts, while the third and fourth parts constitute respectively the horizontal and ascending portions of the inferior part of the duodenum.

Relations.—The *first part (superior part)* is about 5 cm. long, and is the most movable of the four portions; it begins at the pylorus, and ends at the neck of the gall-bladder. It is covered with peritoneum over the whole of its anterior aspect, but it is devoid of peritoneum posteriorly, *except near the pylorus*, where it takes a small part in the formation of the anterior wall of the omental bursa; the right part of the lesser omentum is attached to the upper border, and the greater omentum to the lower border of the proximal half. It is in relation above and in front with

* The small intestine is longer after death owing to the absence of muscle tone; during life its average length in the adult is about 5 metres. B. M. L. Underhill (*Brit. Med. J.*, 1955, 2, 1243) found that in 100 adult subjects shortly after death the small intestine ranged in length from 3.35 to 7.16 metres in women and from 4.88 to 7.85 metres in men, the average length being 5.92 metres in women and 6.37 metres in men. The length was found to be correlated with the height of the individual, but independent of the age. The large intestine was found to be much more constant in length.

the quadrate lobe of the liver and the gall-bladder; above, and on a more posterior plane, with the epiploic foramen; behind, with the gastroduodenal artery, the bile duct and the portal vein, and below and behind, with the head and neck of the

FIG. 1185.—A dissection to show the duodenum and pancreas.



The right and left hepatic veins have been cut away at their points of entry into the inferior vena cava.

The superior hypogastric plexus is shown in front of the sacral promontory and the sympathetic nerves which form it are seen descending across the bifurcation of the aorta, the left common iliac vein and the body of the fifth lumbar vertebra.

pancreas. It is in such close relation with the gall-bladder that it is usually found to be stained by bile after death, especially on its anterior surface.

The *second part (descending part)*, from 8 cm. to 10 cm. long, descends from the

neck of the gall-bladder along the right side of the vertebral column as low as the lower border of the body of the third lumbar vertebra. It is crossed by the transverse colon, the posterior surface of which is connected to the duodenum by a small quantity of areolar tissue. The parts above and below the transverse colon are covered in front with peritoneum. It is in relation, in front, from above downwards, with the duodenal impression on the right lobe of the liver, the transverse colon and the root of the transverse mesocolon, and the small intestine; behind, it has a variable relation to the front of the right kidney in the neighbourhood of its hilus, and is connected to it by loose areolar tissue; the right renal vessels, edge of the inferior vena cava, and Psoas major are also behind it. Its medial side is related to the head of the pancreas and the bile duct; its lateral side, to the right colic flexure. Sometimes a small part of the head of the pancreas is actually embedded in the wall of the second part of the duodenum. The bile-duct and the pancreatic duct come into contact at the medial side of this part of the duodenum. The two ducts enter the wall of the gut obliquely and there unite to form a short, dilated duct which is named the *hepatopancreatic ampulla* (see p. 1454). The narrow, distal end of this ampulla opens on the summit of a papilla, termed the *major duodenal papilla*, which is situated within the second part of the duodenum at the junction of its medial and posterior walls (figs. 1187, 1207), from 8 cm. to 10 cm. distal to the pylorus. The accessory pancreatic duct, when present, opens about 2 cm. proximal to the duodenal papilla, on a small rounded *minor duodenal papilla*.

The *third part (horizontal portion of the inferior part)*, about 10 cm. long, begins at the right side of the lower border of the third lumbar vertebra and passes from right to left, with a slight inclination upwards, in front of the inferior vena cava, and ends in the fourth part in front of the abdominal aorta. Its anterior surface is covered with peritoneum, except near the median plane, where it is crossed by the superior mesenteric vessels and the root of the mesentery. Its posterior surface is uncovered by peritoneum, except towards its left extremity, where the left layer of the mesentery sometimes covers it to a variable extent. This surface rests upon the right ureter, the right Psoas major, the right testicular (or ovarian) vessels, the inferior vena cava and the abdominal aorta (with the origin of the inferior mesenteric artery). The upper surface is in relation with the head of the pancreas; the lower, with the coils of the jejunum.

The *fourth part (ascending portion of the inferior part)*, about 2.5 cm. long, ascends on or immediately to the left of the aorta, as far as the level of the upper border of the second lumbar vertebra, where it turns abruptly forwards (*duodenojejunal flexure*) and is continuous with the jejunum. It lies in front of the left sympathetic trunk, left Psoas major, the left renal and testicular vessels and the inferior mesenteric vein. Along its right border it gives attachment to the upper part of the root of the mesentery, the left layer of which is continued over its anterior surface and left side. To its left there are the left kidney and ureter; above, there is the body of the pancreas; in front, there is the transverse colon and transverse mesocolon (the latter separating the duodenojejunal flexure from the omental bursa and stomach).

The first part of the duodenum, as stated above, possesses a range of movement, but the rest is relatively fixed, and is bound down to neighbouring viscera and the posterior abdominal wall. Radiologically, after a barium meal, the first part of the duodenum is seen as a somewhat triangular homogeneous shadow, called the 'duodenal cap' (Plate XXVI).

The terminal part of the duodenum and the duodenojejunal flexure are fixed by a fibromuscular band termed the *Suspensory muscle of the duodenum*,* which arises from the right crus of the Diaphragm, close to the right side of the œsophagus. It passes downwards and slightly forwards in close relation with the celiac artery (sometimes dividing to enclose this vessel), behind the pancreas and splenic vein and in front of the left renal vein, and is attached to the posterior surface of the upper part of the duodenojejunal flexure, many fibres being continued into the mesentery. Its upper part contains striped muscle fibres, the intermediate part consists of elastic tissue and the lower part generally contains plain muscle. In most cases the Suspensory muscle is attached to the fourth and the third parts of the duodenum as well as to the duodenojejunal flexure; in these circumstances its contraction will tend to increase the

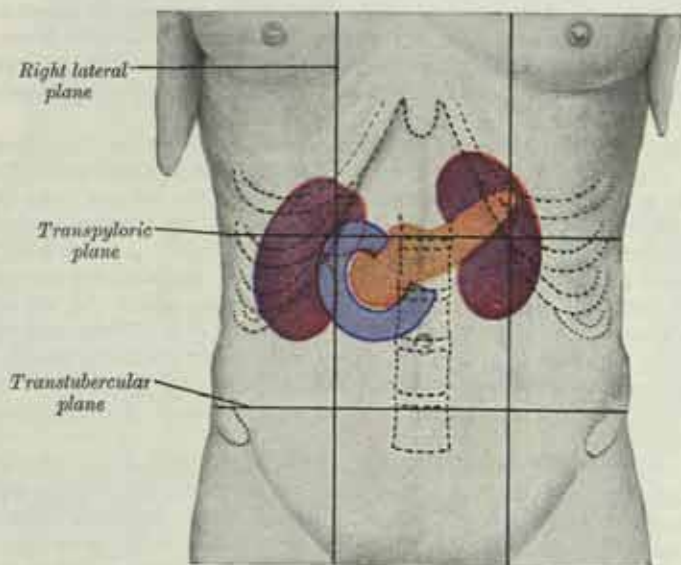
* A. Low, *J. Anat. and Physiol.*, 1907, 42, 73; J. C. Haley and J. K. Peden, *Amer. J. Surgery*, 1943, 59, 546.

angle of the flexure, whereas in those cases where it is attached solely to the flexure it is believed by some that its contraction may narrow the angle of the flexure and tend to cause partial obstruction of the gut at this site.

Vessels and Nerves.—The *arteries* supplying the duodenum are the right gastric and superior pancreaticoduodenal branches of the hepatic, and the inferior pancreaticoduodenal branch of the superior mesenteric. The first part of the duodenum is supplied by a leash of small branches (supraduodenal arteries) of the hepatic artery which run in the right part of the lesser omentum, and a similar leash of vessels from the gastroduodenal artery. These vessels also supply the neighbouring part of the pyloric canal, but there is no anastomosis in the wall of the alimentary canal between these vessels across the pyloroduodenal junction.* The *veins* end in the splenic, superior mesenteric and portal veins. The *nerves* are derived from the celiac plexus.

The rest of the small intestine, about 6 metres long (*see footnote, p. 1423*), extends from the duodenojejunal flexure to the ileocaecal valve, where it ends in the junction of the cæcum and ascending colon of the large intestine; it is arranged

FIG. 1186.—The surface relations of the duodenum, pancreas and kidneys.



in a series of coils or loops which are attached to the posterior abdominal wall by the mesentery. This part of the gut is completely covered with the peritoneum, except for a narrow strip along its mesenteric border, where the two layers of the mesentery diverge from each other to enclose it. It is divided into jejunum and ileum, the former name being given to the upper two-fifths and the latter to the lower three-fifths. There is no morphological line of distinction between these two parts, and the division is arbitrary; but at the same time the character of the intestine gradually undergoes a change from the beginning of the jejunum to the end of the ileum, so that portions of the bowel taken from these two situations present characteristic differences.

The **jejunum** has a diameter of about 4 cm., and is thicker, redder and more vascular than the ileum. The circular folds (p. 1429) of its mucous membrane are large and thickly set, and its villi surpass those of the ileum in size. The aggregated lymphatic follicles (p. 1431) are almost absent in the upper part of the jejunum; in the lower part they are fewer and smaller than in the ileum and tend to assume a circular form. When the jejunum is grasped between the finger and thumb the circular folds can be felt through the wall of the gut; as these folds are absent from the lower part of the ileum, it is possible in this way to distinguish the upper from the lower part of the small intestine.

For the most part the jejunum lies in the umbilical region, but it may extend into any of the surrounding areas. The first coil occupies a recess between

* H. Ogilvie, *Lancet*, 1952, 262, 1077.

the left part of the transverse mesocolon and the anterior surface of the left kidney (p. 1471).

The **ileum** has a diameter of 3.5 cm., and its coats are thinner than those of the jejunum. A few circular folds are present in the upper part of the ileum, but they are small and disappear almost entirely towards its lower end; the aggregated lymphatic follicles are, however, larger and more numerous than in the jejunum. For the most part the ileum is situated in the hypogastric (pubic) and pelvic regions. The terminal part of the ileum usually lies in the pelvis, from which it ascends over the right Psoas major and right iliac vessels to end in the right iliac fossa by opening into the medial side of the junction of the cæcum and ascending colon.

The jejunum and ileum are attached to the posterior abdominal wall by an extensive fold of peritoneum, termed the *mesentery*, which allows of very free movement, so that each coil can accommodate itself to changes in form and position. The mesentery is fan-shaped; its vertebral border or root, about 15 cm. long, is

FIG. 1187.—The interior of the second part of the duodenum, showing the major duodenal papilla.



attached to the posterior abdominal wall along a line running from the left side of the body of the second lumbar vertebra to the right sacro-iliac joint, and crossing successively the third part of the duodenum, the aorta, the inferior vena cava, the right ureter, and right Psoas major (fig. 1167). Its average breadth from the vertebral to the intestinal border is about 20 cm., but is greater in the middle than at its upper and lower ends. The two layers of the mesentery contain the jejunum, ileum, the jejunal and ileal branches of the superior mesenteric blood-vessels, nerves, lacteals, and lymph nodes, together with a variable amount of fat (p. 1410).

Diverticulum ilei (Meckel's diverticulum).—This is a pouch which projects from the lower part of the ileum in about 2 per cent. of subjects. Its average position is about 1 metre above the ileocaecal valve, and its average length about 5 cm. Its calibre is generally similar to that of the ileum, and its blind extremity may be free or may be connected with the abdominal wall or with some other portion of the intestine by a fibrous band. It represents the persistent proximal part of the vitello-intestinal duct, which connects the yolk-sac and the primitive digestive tube in early foetal life (pp. 85, 188). The mucous membrane of the diverticulum has the same structure as that of the neighbouring ileum, but occasionally small regions of the mucous membrane may have a structure similar to that of the body and fundus of the stomach, with oxyntic cells which secrete acid. Sometimes small areas of pancreatic tissue may be found in the wall of the diverticulum.

Structure.—The wall of the small intestine (fig. 1188) is composed of four coats: serous, muscular, submucous and mucous.

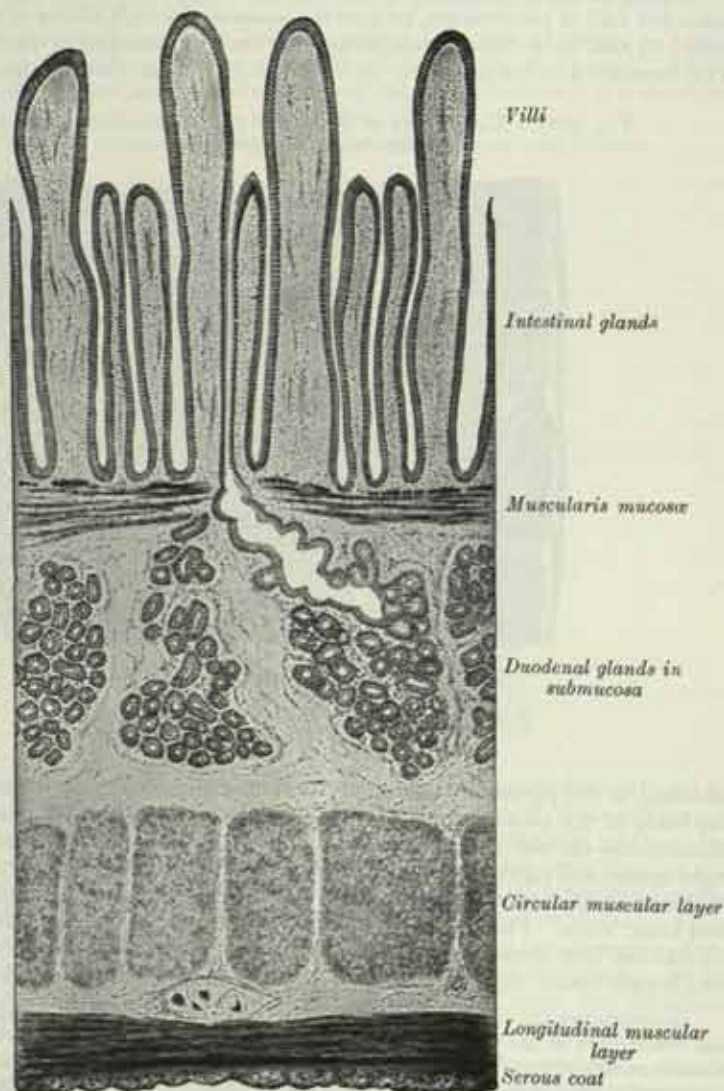
The *serous coat* is formed of peritoneum.

The *muscular coat* is thicker in the upper than in the lower part of the small intestine; it consists of an external longitudinal and an internal circular layer of non-striped muscular fibres. The *longitudinal layer* is thin; the *circular layer* is thick, and composed of fibres of considerable length.

The *submucous coat* unites the mucous and muscular layers. It consists of loose, areolar tissue containing blood-vessels, lymph vessels and nerves.

The *mucous membrane* is thick and highly vascular in the upper part of the small intestine, but thinner and less vascular in the lower part. It consists of the following

FIG. 1188.—A section through the duodenum of a cat. $\times 60$. (From Sharpey-Schafer's *Essentials of Histology*.)



structures: next to the submucous coat there is the *muscularis mucosae*, which consists of an outer longitudinal and inner circular layer of unstriated muscular fibres; internal to the muscularis mucosae there is a quantity of retiform tissue, enclosing lymphocytes in its meshes, and in which the blood-vessels and nerves ramify; lastly, a basement membrane, supporting a single layer of tall columnar cells. The cells are granular in appearance, and each possesses a clear oval nucleus. Their superficial, unattached ends present a distinct layer of highly refracting material, marked by vertical striae (the *striated border*). The striated border* (or brush border) is very

* F. R. Johnson and J. H. Kugler, *J. Anat., Lond.*, 1953, **87**, 247; D. Brandes, H. Zetterqvist and H. Sheldon, *Nature, Lond.*, 1956, **177**, 382.

rich in the enzyme, alkaline phosphatase, and is concerned in the process of *active* absorption. Electron microscope study of the brush border in the intestinal epithelium of the mouse shows it to be composed of minute parallel cylindrical projections of the cytoplasm, called microvilli (about 1μ long and 0.1μ broad). The alkaline phosphatase is mainly distributed in the intercyllindrical spaces. Goblet-cells occur at intervals in the epithelial layer. It has been shown in a number of mammals that epithelial cells, produced by the incessant mitotic activity in the intestinal glands, pass upwards along the sides of the villi, from the tips of which they are eventually shed. In this way there is a continual renewal of the epithelial covering of the villi, and there is evidence that a similar process occurs in man.*

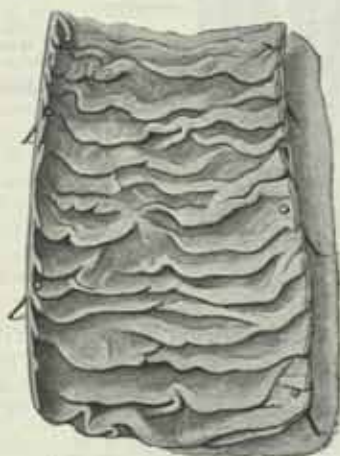
The following structures are contained within or belong to the mucous membrane :

Circular folds.
Villi.
Intestinal glands.

Duodenal glands.
Solitary lymphatic follicles.
Aggregated lymphatic follicles.

The **circular folds** (fig. 1189) are large transverse folds of mucous membrane which project into the lumen of the bowel. They are composed of reduplications of the mucous membrane, the two layers of the fold being bound together by submucous tissue; unlike the folds in the stomach they are permanent, and are not obliterated when the intestine is distended. The majority extend transversely round the intestine for about one-half or two-thirds of its circumference, but some form complete circles, some bifurcate and join adjacent folds, and others have a spiral direction; the latter usually extend a little more than once round the bowel, but occasionally two or three times. The larger folds are about 8 mm. in depth at their broadest part; but the greater number are of smaller size. The larger and smaller folds alternate with each other. Circular folds are not found at the commencement of the duodenum, but begin to appear about 2.5 to 5 cm. beyond the pylorus. Distal to the point where the bile and pancreatic ducts enter the duodenum, they are very large and closely approximated. In the upper one-half of the jejunum they are large and numerous, but from this point, down to the middle of the ileum, they diminish considerably in size. In the lower part of the ileum they are almost entirely absent; hence the comparative thinness of this portion of the intestine, as compared with the duodenum and jejunum. The circular folds retard the passage of the food and afford an increased surface for absorption (Pl. XXVII).

FIG. 1189.—The interior of a portion of the upper part of the jejunum, showing the circular folds.



The **intestinal villi** are highly vascular processes, just visible to the naked eye; they project from the mucous membrane of the whole of the small intestine, and give to its surface a velvety appearance. They are large and numerous in the duodenum and jejunum, but are smaller and fewer in the ileum.

Structure of the villi (figs. 1190, 1191).—The essential parts of a villus are: the lacteal vessel, the blood-vessels, the epithelium, the basement-membrane and the muscular tissue of the mucosa, all being supported and held together by retiform tissue.

The *lacteals* are in some cases double, and in some animals multiple, but usually there is a single vessel. Situated in the axis of the villus, each commences by a dilated blind extremity near to, but not quite at, the summit of the villus. The wall is composed of a single layer of endothelial cells.

The *muscular fibres* are derived from the muscularis mucosæ, and are arranged in bundles around the lacteal vessel, extending from the base to the summit of the villus, and giving off, laterally, individual muscle-cells, which are enclosed by the reticulum, and by it are attached to the basement-membrane and to the lacteal. Contraction of the muscularis mucosæ therefore has the effect of 'milking' the lacteals.

The *blood-vessels* (fig. 1192) form a plexus under the basement-membrane, and are enclosed in the reticular tissue.

* C. P. Leblond and C. E. Stevens, *Anat. Rec.*, 1948, 100, 357; R. M. H. McMinn, *J. Anat., Lond.*, 1954, 88, 527.

These structures are surrounded by the *basement-membrane*, which is made up of a layer of hyaline amorphous intercellular material, and upon this is placed a layer of *columnar epithelium*, the characteristics of which have been described above. The *retiform tissue* forms a network (fig. 1190) in the meshes of which a number of leucocytes are found.

FIG. 1190.—A vertical section through a villus of the small intestine of a dog. $\times 80$.

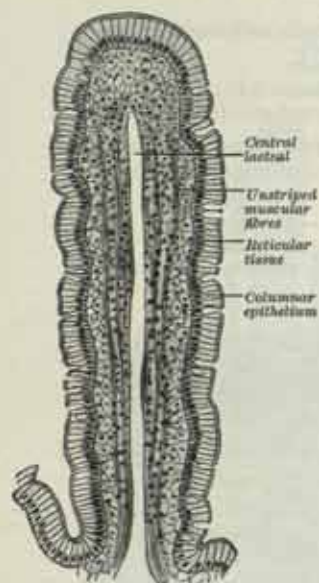
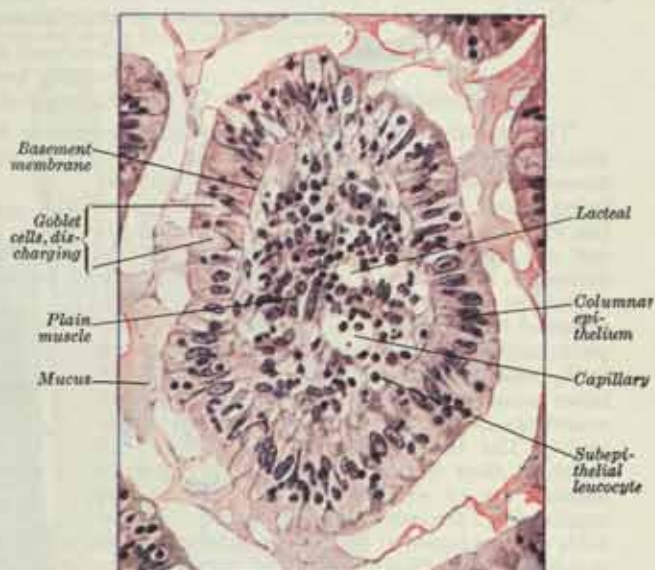
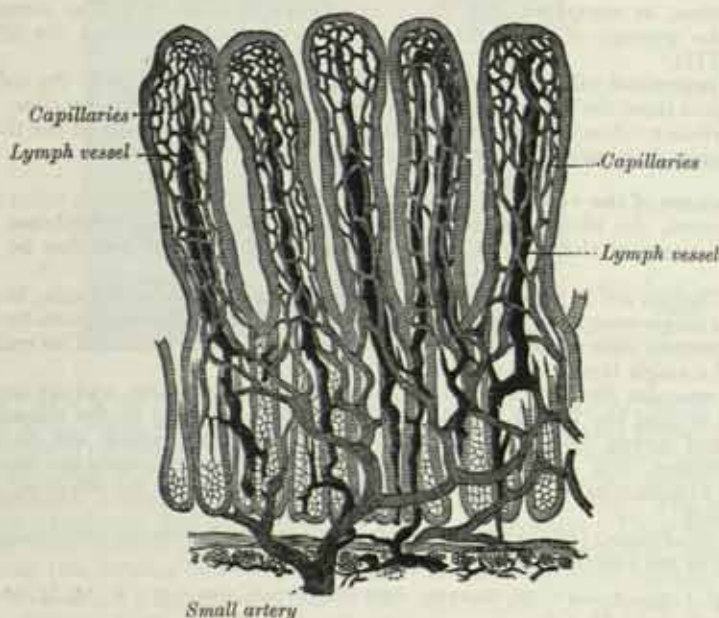


FIG. 1191.—A transverse section through a villus of the human jejunum. Stained with haematoxylin and eosin. $\times 380$.



The **intestinal glands** (fig. 1193) are found in considerable numbers over every part of the mucous membrane of the small intestine. They are simple tubular glands, arranged perpendicularly to the surface, upon which they open by small circular apertures. Their orifices may be seen with the aid of a lens as minute dots scat-

FIG. 1192.—The villi of the small intestine, showing the blood vessels and the lymph vessels. (Cadiat.)



tered between the villi. Their walls are thin, consisting of a basement-membrane lined with columnar epithelium, and covered on their exterior with capillary vessels. The deeper cells, especially in the duodenal glands, contain granules which stain characteristically with phosphotungstic hæmatoxylin and are termed *granules of Paneth*.

The **duodenal glands** are limited to the duodenum (fig. 1188), and are found in the *submucous areolar tissue*, i.e. they penetrate deep to the muscularis mucosæ. They are largest and most numerous near the pylorus, forming an almost complete layer in the first part, and upper half of the second part, of the duodenum; beyond this they gradually diminish in number and disappear at the junction of the duodenum and jejunum. They are small, compound, acinotubular glands, each consisting of a number of alveoli lined with short columnar epithelium and opening by a duct on the inner surface of the intestine.

Between the cells lining the intestinal glands, and less commonly among those covering the villi, lie pyramidal or columnar cells, the cytoplasm of which contains granules that have an affinity for silver salts, by which they are stained black, and for chromium salts, by which they are stained brown. They are called *enterochromaffin cells* or *argentaffin cells*. They usually occur singly (not in groups) among the epithelial cells and their bases rest on the basement membrane. They occur in all parts of the alimentary canal, as well as in the pancreatic and bile ducts, but are most numerous in the duodenum and vermiform appendix. They may give rise to pathological tumours (carcinoidosis). The origin, nature and function of these cells are not clearly understood. Some believe they produce a hormone (5-hydroxytryptamine) which stimulates plain muscle. This substance is also present in blood platelets which probably absorb it from the cells in the alimentary canal.

The **solitary lymphatic follicles** are found scattered throughout the mucous membrane of the small intestine, but are most numerous in the lower part of the ileum. Their free surfaces are covered with rudimentary villi, except at the summits, and each follicle is surrounded by the openings of the intestinal glands. Each consists of a dense, interlacing, retiform tissue closely packed with lymphocytes, and permeated by an abundant, capillary network. The interspaces of the retiform tissue are continuous with larger lymph spaces which surround the follicle, and by this means they are enabled to communicate with the lacteal system. They are situated partly in the submucous tissue, and partly in the mucous coat, where they form slight projections of its epithelial layer.

The **aggregated lymphatic follicles** (Peyer's patches) (fig. 1194) form circular or oblong patches, from twenty to thirty in number, and varying in length from 2 cm. to 10 cm. Like the other collections of lymphoid tissue in the body (except the lymph nodes), they are best marked in the young subject, become indistinct in middle age, and usually disappear altogether in advanced life. They are largest and most numerous in the ileum. In the lower part of the jejunum they are small, circular and few in number. They are occasionally seen in the duodenum. They are placed lengthwise in the intestine, and are situated in the portion of the tube most distant from the attachment of the mesentery. Each patch is formed of a group of solitary lymphatic follicles covered with columnar epithelium; the patches do not, as a rule, possess villi on their free surfaces. They are freely supplied with blood-vessels, which form an abundant plexus around each follicle and give off fine branches to permeate the lymphoid tissue in the interior of the follicle. The plexuses of lymph vessels are especially abundant around these patches. In typhoid fever, ulceration of these aggregated lymphatic follicles may occur; the ulcers are thus oval in shape, their long axes are in the long axis of the bowel (so that subsequent fibrosis does not constrict the gut), they are present chiefly in the lower part of the ileum, and are situated on or near the antimesenteric border of the gut.

Vessels and Nerves.—The jejunum and ileum are supplied by the superior mesenteric artery, the jejunal and ileal branches of which, having reached the attached border of the bowel, run between the serous and muscular coats. From these vessels numerous branches are given off, which pierce the muscular coat, supplying it and forming an intricate plexus in the submucous tissue. From this plexus minute vessels

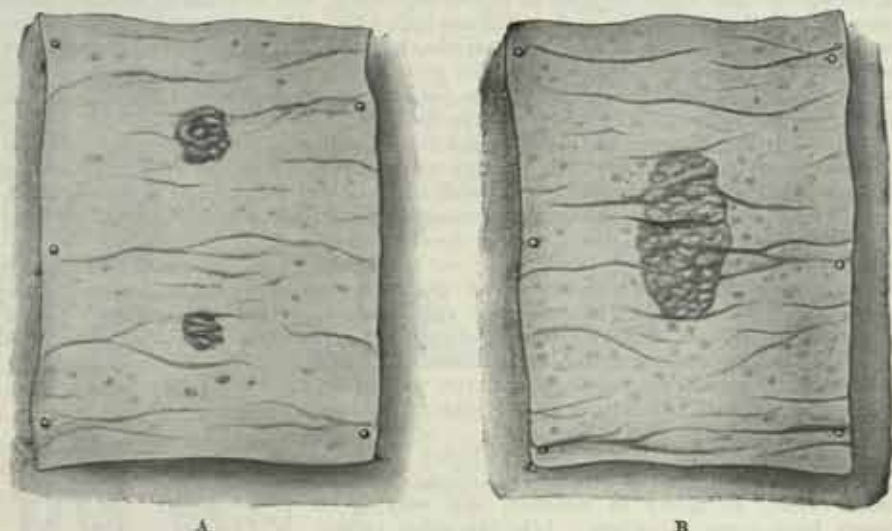
FIG. 1193.—An intestinal gland from the human small intestine. Stained with hæmatoxylin and eosin. $\times 250$.



pass to the glands and villi of the mucous membrane. The anastomoses between the terminal intestinal branches are by no means free, and there is a distinct tendency for the alternate vessels to be distributed to opposite sides of the gut. The *veins* have a course and arrangement similar to the arteries. The *lymph vessels* of the small intestine [lacteals] are arranged in two sets, viz. those of the mucous membrane and those of the muscular coat. The lymph vessels of the villi commence in these structures in the manner described on p. 1429. They form an intricate plexus in the mucous and sub-mucous tissue, being joined by the lymph vessels from the lymph spaces at the bases of the solitary follicles and from there pass to larger vessels at the mesenteric border of the gut. The lymph vessels of the muscular coat are situated to a great extent between the two layers of muscular fibres, where they form a close plexus; throughout their course they communicate freely with those from the mucous membrane, and open in the same manner as these into the origins of the lacteal vessels at the attached border of the gut.

The *nerves* of the small intestine are derived from the vagus and splanchnic nerves

FIG. 1194.—Aggregated lymphatic follicles. A, from the upper part, and B, from the lower part, of the ileum.



through the celiac ganglia and the plexuses around the superior mesenteric artery. They run to the *myenteric plexus* (p. 1423) of nerves and ganglia, situated between the circular and longitudinal layers; from this plexus filaments are distributed to the muscular coats of the intestine. From the myenteric plexus a secondary plexus, termed the *submucous plexus*, is derived, and is formed by branches which have perforated the circular muscular layer. This plexus also contains ganglia from which the nerve-fibres pass to the muscularis mucosæ and to the mucous membrane. The nerve-bundles of the submucous plexus are finer than those of the myenteric plexus. The nerve-cells in both plexuses are essentially parasympathetic (vagal).^{*} In general the sympathetic is inhibitory to the peristaltic movements of the alimentary canal, but constricts the sphincters and also the muscularis mucosæ. While the parasympathetic is generally an augmentor of the peristaltic movements and an inhibitor of the sphincters, the result of stimulation of the parasympathetic appears to depend on the state of contraction or relaxation of the organ at the time of stimulation. The parasympathetic is also augmentor to the secretion of gastric juice.

THE LARGE INTESTINE [INTESTINUM CRASSUM]

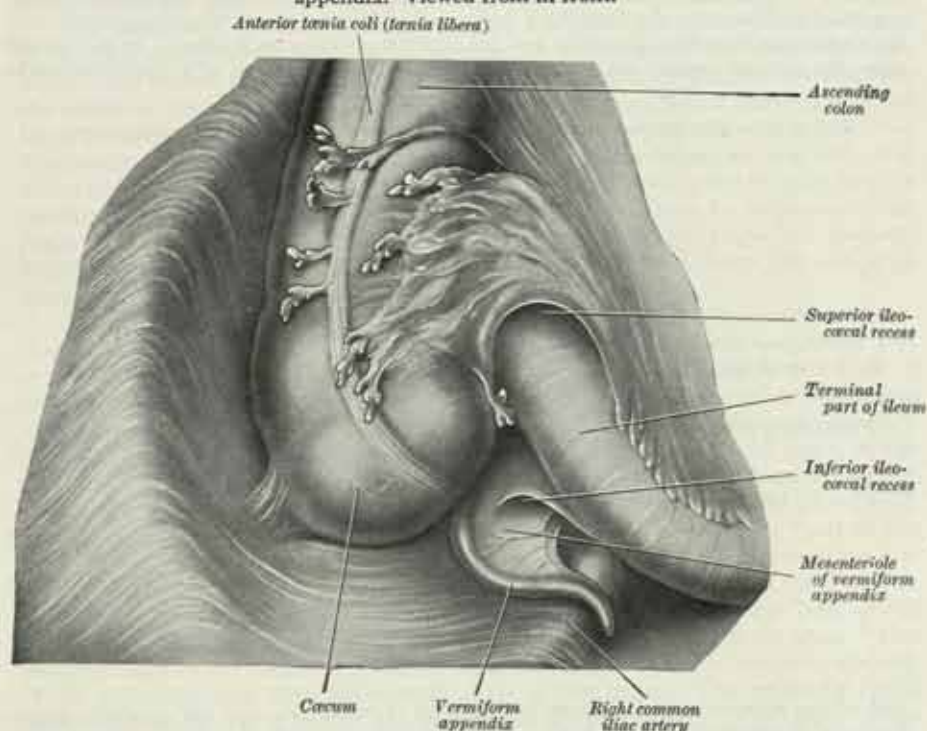
The **large intestine** extends from the end of the ileum to the anus, and is about 1·5 metres long. Its calibre is largest at its commencement at the cæcum, and gradually diminishes as far as the rectum, where there is a dilatation of considerable size just above the anal canal. In appearance, structure, size and arrangement it presents certain differences from the small intestine. (1) It has a greater calibre. (2) For the most part, it is more fixed in position. (3) Its longitudinal muscular fibres (see p. 1446) form three longitudinal bands or *tæniæ coli*. (4) Since these

^{*} C. J. Hill, *Philos. Trans.*, B. 215. 355, 1926-27.

tæniæ are shorter than the circular muscular coat, the colon is puckered and sacculated, the sacculations being known as *haustrations*. (5) Little, peritoneum-covered, fatty projections, termed *appendices epiploicae*, are found scattered over the free surface of the whole of the large intestine, with the exceptions of the cæcum, the vermiform appendix and the rectum.

In its course the large intestine describes an arch which usually encloses the convolutions of the small intestine. It commences in the right iliac region, in a dilated part, termed the *cæcum* (fig. 1195). It ascends through the right lumbar and hypochondriac regions to the under surface of the liver; here it bends [the *right colic flexure*] (fig. 1185) to the left, and, curving with a downward and a forward

FIG. 1195.—The terminal part of the ileum, the cæcum and the vermiform appendix. Viewed from in front.



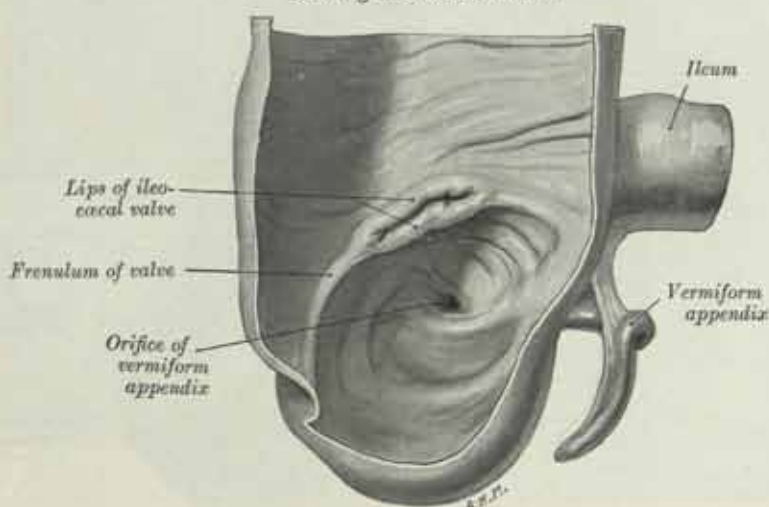
convexity, passes, as the *transverse colon*, across the abdomen to the left hypochondriac region; it then bends again [the *left colic flexure*] (fig. 1185), and descends through the left lumbar and iliac regions to the pelvis, where it forms a loop called the *sigmoid colon* (fig. 1199); from this it is continued along the lower part of the posterior wall of the pelvis to the anus. It is divided into the cæcum, the colon, the rectum and the anal canal.

The *cæcum* (fig. 1195), which is the commencement of the large intestine, lies in the right iliac fossa. Its surface projection occupies the triangular area bounded by the right lateral plane, the transtubercular plane and the fold of the groin. It is a large sac which has a blind lower end but is continuous above with the ascending colon, and at the point where the one passes into the other the ileum opens into the large intestine from the medial side. Its average length is about 6 cm. and its breadth about 7.5 cm. It is situated in the right iliac fossa above the lateral half of the inguinal ligament: it rests on the Iliacus and on the Psoas major, being separated from both muscles by their covering fasciæ and the peritoneum, and the retro-cæcal recess of the peritoneum (p. 1412) which frequently contains the vermiform appendix. In addition, the lateral cutaneous nerve of the thigh intervenes between it and the Iliacus. In front it is usually in contact with the anterior abdominal wall, but the greater omentum, and, if the cæcum is empty, some coils of small intestine, may lie in front of it. As a rule, it is entirely enveloped by peritoneum, but in about 5 per cent. of cases (Berry) the peritoneal covering is incomplete, the

upper part of the posterior surface being uncovered, and connected to the iliac fascia by areolar tissue. The cæcum enjoys a considerable amount of movement, so that it may become herniated down the right inguinal canal, and it has occasionally been found in an inguinal hernia on the left side.

The cæcum varies in shape, but, according to Treves, it may be classified under one of four types. In early foetal life it is short, conical, and broad at the base, with its apex turned upwards and medially towards the ileocaecal junction. As the foetus grows, the cæcum increases in length more than in breadth, so that it forms a longer tube and lacks the broad base, but still has the same inclination of the apex towards the ileocaecal junction. As development goes on, the lower part of the tube ceases to grow and the upper part becomes greatly increased, so that at birth the narrow vermiform appendix hangs from the apex of a conical cæcum. This is the infantile form and as it persists throughout life in about 2 per cent. of subjects, it was regarded by Treves as the *first* of his four types of human cæca. The three *tæniæ coli* (p. 1446) start from the appendix and are equidistant from each other. In the *second* type, the conical cæcum has become quadrate by the outgrowth of a saccule on each

FIG. 1196.—The interior of the cæcum and the lower end of the ascending colon, showing the ileocaecal valve.



side of the anterior *tænia*. These saccules are of equal size, and the appendix arises from the depression between them, instead of from the apex of a cone. This type is found in about 3 per cent. of subjects. The *third* type is the normal type for man. Here the two saccules, which in the second type were uniform, have grown at unequal rates: the right with greater rapidity than the left. In consequence of this an apparently new apex has been formed by the downward growth of the right saccule, and the original apex, with the appendix attached, is pushed over to the left towards the ileocaecal junction. The three *tæniæ* still start from the base of the vermiform appendix, but they are now no longer equidistant from each other, because the right saccule has grown between the anterior and posterolateral *tæniæ*, pushing them over to the left. This type occurs in about 90 per cent. of subjects. The *fourth* type is merely an exaggerated condition of the third; the right saccule is still larger, and at the same time the left saccule has become atrophied, so that the original apex of the cæcum, with the vermiform appendix, is close to the ileocaecal junction, and the anterior *tænia* courses medially to the same situation. This type is present in about 4 per cent. of subjects.

The ileocaecal valve (fig. 1196).—The lower end of the ileum opens into the medial and posterior aspect of the large intestine, at the point of junction of the cæcum with the colon. The ileocaecal orifice is represented on the surface at the point of intersection of the right lateral and transtubercular planes; about 2 cm. below this point the vermiform appendix opens into the cæcum. The opening is provided with a valve, consisting of two segments or lips, which project into the lumen of the large intestine. If the intestine has been inflated and dried, the lips are of a semilunar shape. The upper lip, nearly horizontal in direction, is attached to the

line of junction of the ileum with the colon; the lower lip, the longer and more concave, is attached to the line of junction of the ileum with the cæcum. At the ends of the aperture the two segments of the valve coalesce, and are continued as narrow membranous ridges for a short distance, forming the *frenula* of the valve. The left or anterior end of the aperture is rounded; the right or posterior is narrow and pointed. In the fresh condition, or in specimens which have been hardened *in situ*, the lips of the valve project as thick folds into the lumen of the cæcum, and the opening may present the appearance of a slit or may be somewhat oval in shape. The circular muscle coat of the terminal part of the ileum is thickened to form a sphincter.

Each lip of the valve is formed by a reduplication of the mucous membrane and of the circular muscular fibres of the intestine, the longitudinal fibres and peritoneum being continued uninterruptedly from the small to the large intestine.

The surfaces of the valve directed towards the ileum are covered with villi and present the characteristic structure of the mucous membrane of the small intestine; while those turned towards the large intestine are destitute of villi and marked with the orifices of the numerous tubular glands peculiar to the mucous membrane of the large intestine. It was formerly maintained that this valve prevented reflux from the cæcum into the ileum, but in all probability it acts as a sphincter round the end of the ileum and prevents the contents of the ileum from passing too quickly into the cæcum; the valve is kept in a condition of tonic contraction by impulses which reach it through the sympathetic nerves. The taking of food into the stomach initiates contraction of the ileum and the passage of ileal contents into the large intestine through the ileocaecal opening (gastro-ileal reflex).

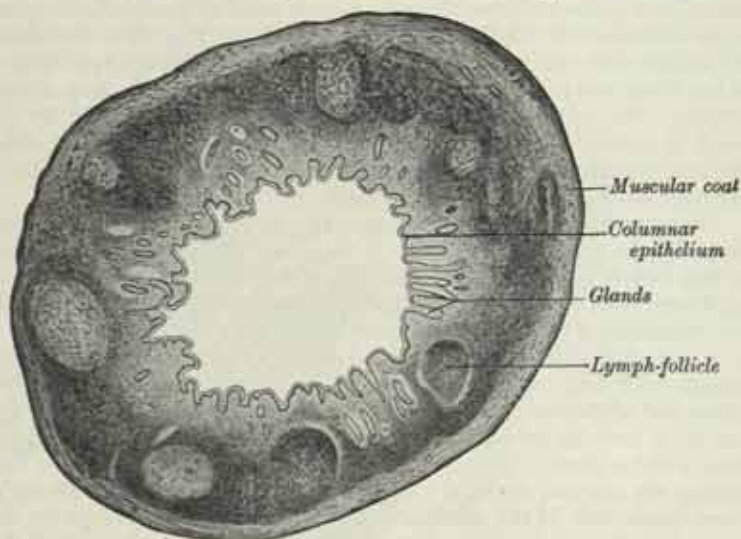
The **vermiform appendix** (figs. 1195, 1196 and Pl. XXIX) is a narrow, worm-shaped tube, which springs from the posteromedial wall of the cæcum, 2 cm. or less below the end of the ileum, and may occupy one of several positions: * (a) it may lie behind the cæcum and the lower part of the ascending colon (*retrocaecal and retrocolic*), (b) it may hang down over the brim of the pelvis (*pelvic or descending*), in which case it lies in close relation to the right uterine tube and ovary in the female, (c) it may lie below the cæcum (*subcaecal*), (d) it may lie in front of the terminal part of the ileum and may then be in contact with the anterior abdominal wall, and (e) it may lie behind the terminal part of the ileum. McBurney marked the base of the appendix opposite the junction of the lower and middle thirds of the line joining the anterior superior iliac spine to the umbilicus (*McBurney's point*). The three teniae coli of the ascending colon and cæcum converge on the base of the appendix, where they merge into the longitudinal muscular coat of the latter. The anterior tenia of the cæcum is generally distinct and can be easily traced to the root of the appendix, thus affording a ready guide to that organ. The appendix varies from 2 cm. to 20 cm. in length, the average being about 9 cm. It is longer in the child than in the adult and may atrophy and become smaller after mid-adult life. It is connected by a short mesenteriole to the lower part of the mesentery of the ileum. This fold, in the majority of cases, is more or less triangular in shape, and as a rule extends along the entire length of the tube. The artery to the appendix, a branch of the lower division of the ileo-colic artery (p. 803), runs behind the terminal part of the ileum and enters the mesenteriole of the appendix a short distance from the base of the appendix. Here it gives off a recurrent branch which anastomoses at the base of the appendix with a branch of the posterior caecal artery, the anastomosis sometimes being of considerable size. The main appendicular artery runs towards the tip of the appendix, lying at first near to and afterwards in the free border of the appendicular mesenteriole. The terminal part of the artery, however, lies actually on the wall of the appendix and may become thrombosed in inflammation of the appendix, resulting in gangrene of the distal part of the appendix. The canal of the vermiform appendix is small, and communicates with the cæcum by an orifice which is placed below and a little behind the ileocaecal opening. The orifice is sometimes guarded by a semilunar valve formed by a fold of mucous membrane. The lumen of the appendix may be partially or completely obliterated after mid-adult life. In view of its rich blood-supply and histological differentiation, the vermiform appendix is probably more correctly to be regarded as a specialised than

* In 10,000 subjects, Wakeley (*J. Anat.*, 67, 1933) found the vermiform appendix to be retrocaecal and retrocolic in 65.28 per cent., pelvic in 31.01 per cent., subcaecal in 2.26 per cent., pre-ileal in 1.0 per cent., and post-ileal in 0.4 per cent.

as a degenerate, vestigial structure. The configuration of the cæcum and appendix in man and the anthropoid apes is probably less primitive than in the monkeys.

Structure.—The coats of the vermiform appendix are the same as those of the intestine: serous, muscular, submucous and mucous. The *serous* coat forms a complete investment for the tube, except along the narrow line of attachment of its mesentery. The *longitudinal muscular fibres* do not form three bands as in the greater part of the large intestine, but form a uniformly thick layer which invests the whole organ, except at one or two points where both the longitudinal and circular layers may be deficient, so that the peritoneal and submucous coats are contiguous over small areas. The *circular muscular fibres* form a thicker layer than the longitudinal fibres, and are separated from them by a small amount of connective tissue. The *submucous* coat is well developed, and contains a large number of masses of lymphoid tissue which cause the mucous membrane to bulge into the lumen and so render the latter of small size and irregular shape. The *mucous membrane* is lined with columnar

FIG. 1197.—A transverse section through the human vermiform appendix. $\times 20$.



epithelium and resembles that of the rest of the large intestine, but the intestinal glands are fewer in number (fig. 1197).

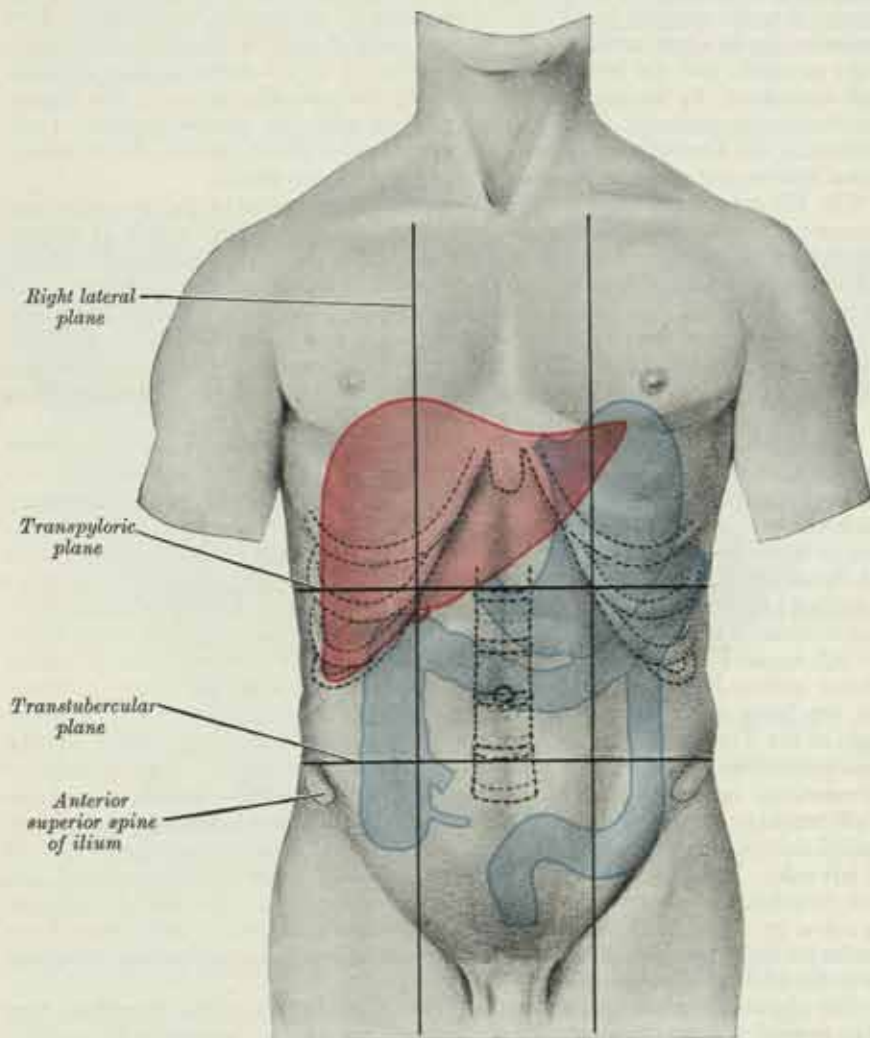
The **colon** is divided into four parts: the ascending, transverse, descending and sigmoid.

The **ascending colon**, about 15 cm. long, is smaller in calibre than the cæcum. It begins at the cæcum, and ascends to the under surface of the right lobe of the liver, where it is lodged in a shallow depression, termed the colic impression; here it bends abruptly forwards and to the left, forming the *right colic flexure* (fig. 1185). In surface projection it runs upwards immediately to the right of the right lateral plane, from the transtuberular plane to midway between the subcostal and transpyloric planes. It is covered with peritoneum on its front and sides. Its posterior surface is connected by areolar tissue to the fascia over the Iliacus, iliolumbar ligament, Quadratus lumborum and the aponeurotic origin of the Transversus abdominis; and to the perirenal fascia in front of the lower and lateral part of the right kidney. The lateral cutaneous nerve of the thigh, the fourth lumbar artery (as a rule) and, sometimes, the ilio-inguinal and iliohypogastric nerves cross behind it. Sometimes it is completely invested with peritoneum, and it then possesses a distinct but narrow mesocolon.* It is in relation, in front, with the convolutions of the ileum, the right edge of the greater omentum and the abdominal wall.

* Treves examined one hundred subjects and found that in fifty-two there was neither an ascending nor a descending mesocolon; in fourteen both were present; while in twelve there was an ascending, and in twenty-two a descending, mesocolon. It follows, therefore, that when lumbar colotomy is performed, a mesocolon may be expected upon the left side in 36 per cent. of all cases, and on the right in 26 per cent.—*The Anatomy of the Intestinal Canal and Peritoneum in Man*, 1885, p. 55.

The *right colic flexure* comprises the terminal part of the ascending colon and the commencement of the transverse colon, which turns downwards, forwards and to the left. Behind, it is in relation with the lower and lateral part of the anterior surface of the right kidney. Above and anterolaterally, it is related to the right lobe of the liver; anteromedially, to the second part of the duodenum and the fundus of the gall-bladder. It is not covered by peritoneum on its posterior surface, so that this

FIG. 1198.—The surface relations of the stomach, liver and large intestine.



surface is in direct contact with the renal fascia. The flexure is not so acute as the left colic flexure.

The **transverse colon** (fig. 1174), about 50 cm. long, begins at the right colic flexure, in the right hypochondriac region, and, passing across the abdomen into the left hypochondriac region, curves sharply on itself, downwards and backwards, beneath the lateral end of the spleen, forming the *left colic flexure*. In its course across the abdomen it describes an arch, the concavity of which is usually directed backwards and upwards; towards its splenic end there is often an abrupt U-shaped curve which may descend lower than the main curve. Its surface projection is drawn from a point, situated immediately lateral to the right lateral plane and midway between the subcostal and transpyloric planes, to the umbilicus, and then upwards and to the left to a point a little above and lateral to the intersection of the left lateral and transpyloric planes. The precise position occupied by the transverse

colon is difficult to define, for it not only shows variations from individual to individual but its position varies in the same individual from time to time. Very commonly it lies in the lower umbilical or upper hypogastric region, but it is often found at a higher level, especially in formalin-hardened subjects. It frequently descends in a V-shaped manner, the apex of the V reaching well below the level of the iliac crests (see p. 1399). The posterior surface of its right extremity is devoid of peritoneum, and is attached by areolar tissue to the front of the second part of the duodenum and the head of the pancreas. Between the head of the pancreas and the left colic flexure, the transverse colon is almost completely invested by peritoneum, and is connected to the anterior border of the pancreas by the *transverse mesocolon*. It is in relation, by its upper surface, with the liver and gall-bladder, the greater curvature of the stomach, and the lateral end of the spleen; by its under surface, with the small intestine; by its anterior surface with the posterior layers of the greater omentum; its posterior surface is in relation with the second portion of the duodenum, the head of the pancreas, the upper end of the mesentery, the duodeno-jejunal flexure and some of the coils of the jejunum and ileum.

The *left colic flexure* (fig. 1185) is situated at the junction of the transverse and descending parts of the colon in the left hypochondriac region, and is in relation with the lateral end of the spleen and the tail of the pancreas, above, and with the anterior aspect of the left kidney, medially; the flexure is so acute that the end of the transverse colon usually lies in contact with the front of the descending colon. The left colic flexure lies at a higher level than, and on a plane posterior to, the right colic flexure (Pl. XXVIII), and is attached to the Diaphragm, opposite the tenth and eleventh ribs, by a peritoneal fold, named the *phrenicocolic ligament*, which lies below the lateral end of the spleen (p. 1410).

The *descending colon* (fig. 1185), about 25 cm. long, passes downwards through the left hypochondriac and lumbar regions. At first it follows the lower part of the lateral border of the left kidney and then, at the lower pole of that organ, it descends, in the angle between Psoas major and Quadratus lumborum, to the crest of the ilium; it then curves downwards and medially in front of the Iliacus and Psoas major, and ends in the sigmoid colon at the inlet of the true pelvis.* In surface projection it passes downwards, just lateral to the left lateral plane, from a point situated a little above and to the left of the intersection of the transpyloric and left lateral planes, as far as the fold of the groin. The peritoneum covers its anterior surface and sides, while its posterior surface is connected by areolar tissue with the fascia over the lower and lateral part of the left kidney, the aponeurotic origin of the Transversus abdominis, the Quadratus lumborum, the Iliacus and the Psoas major (fig. 1205). Numerous structures cross behind it. They include:—the subcostal vessels and nerve, the iliohypogastric and ilio-inguinal nerves, the fourth lumbar artery (as a rule), the lateral femoral cutaneous, femoral and genito-femoral nerves, the testicular (or ovarian) vessels and the external iliac artery, all of the left side. The descending colon is smaller in calibre, more deeply placed, and more frequently covered with peritoneum on its posterior surface, than the ascending colon (p. 1436, footnote). Anteriorly it is related to coils of the jejunum, except in its lower part, which can be felt through the anterior abdominal wall when the abdominal muscles are relaxed.

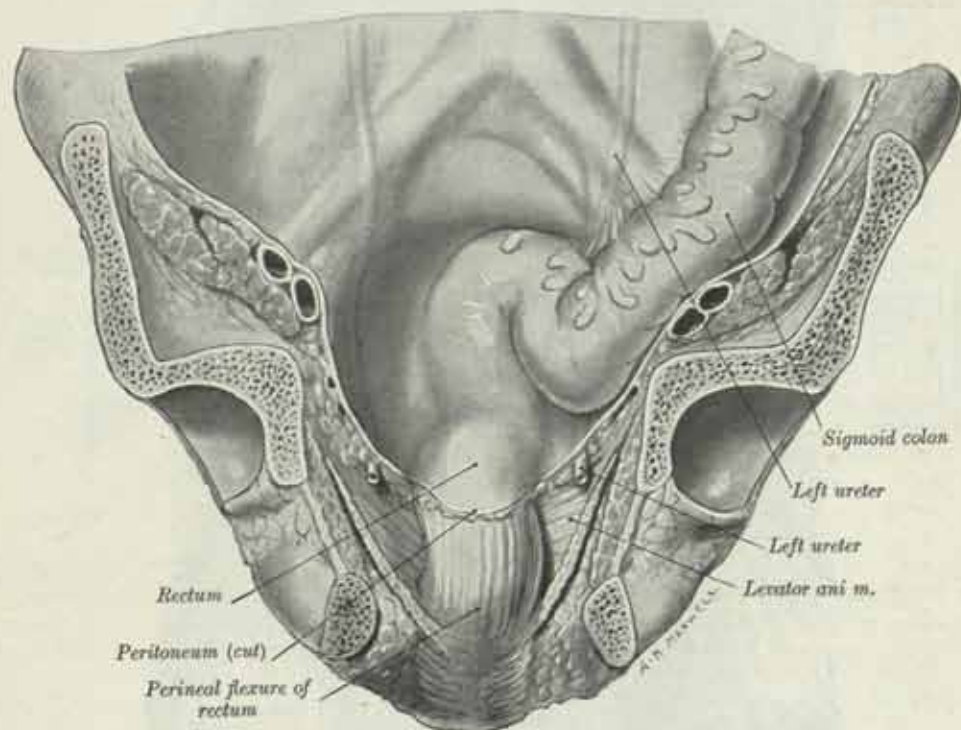
The *sigmoid colon* (or pelvic colon) (fig. 1199) begins at the inlet of the true pelvis, where it is continuous with the descending colon; it forms a loop which varies greatly in length, but averages about 40 cm., and normally lies within the pelvis. The loop consists of three parts; the first part descends in contact with the left pelvic wall; the second crosses the pelvic cavity, between the rectum and bladder in the male, and the rectum and uterus in the female, and may come into contact with the right pelvic wall; the third arches backwards and reaches the median plane at the level of the third piece of the sacrum, where it bends downward and ends in the rectum. The sigmoid colon is completely surrounded by peritoneum, which forms a mesentery, termed the *sigmoid mesocolon* (p. 1410); this diminishes in length from the centre towards the ends of the loop, where it disappears, so that the loop is fixed at its junctions with the descending colon and rectum, but enjoys a considerable range of movement in its central portion. Its relations are therefore subject to considerable variation. *Laterally* it is related to

* The descending colon is sometimes described as ending at the level of the iliac crest, the part between that level and the inlet of the true pelvis being named the *iliac colon*.

the external iliac vessels, the obturator nerve, the ovary (in the female), the ductus deferens (in the male) and the lateral pelvic wall. *Posteriorly* it is related to the internal iliac vessels, the ureter, the Piriformis and the sacral plexus, all of the left side. *Inferiorly* it rests on the bladder, in the male, and on the uterus and bladder, in the female. *Above* and on its *right side*, it is in contact with the terminal coils of the ileum.

The position and shape of the sigmoid colon vary very much, and depend on (a) its length; (b) the length and freedom of its mesocolon; (c) the condition of distention; when distended it rises out of the pelvis into the abdominal cavity, and when empty it sinks again into the pelvis; (d) the condition of the rectum and bladder (and the uterus, in the female); when these organs are distended the sigmoid colon tends to rise, and conversely.

FIG. 1199.—An oblique coronal section through the pelvis to expose the rectum from in front.

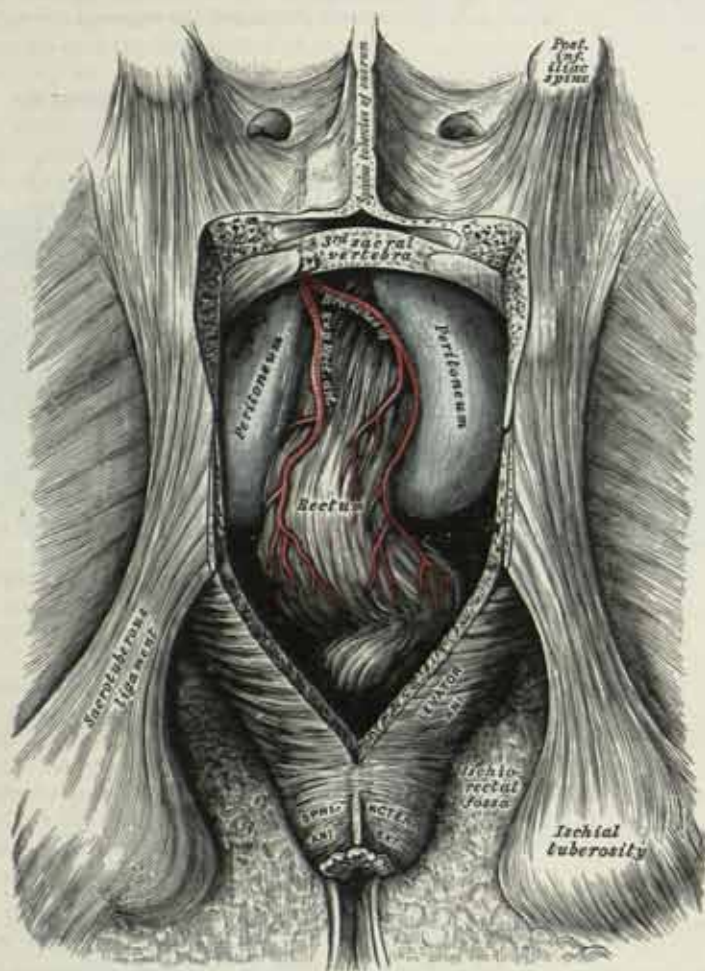


The **rectum** (figs. 1199 to 1202) is continuous above with the sigmoid colon at the level of the third sacral vertebra, the junction being indicated by the lower end of the sigmoid mesocolon. From its origin it descends, following the concavity of the sacrum and coccyx, forming an anteroposterior curve known as the *sacral flexure* of the rectum. It thus passes at first downwards and backwards, then downwards, and finally downwards and forwards to become continuous with the anal canal by passing through the pelvic diaphragm. The anorectal junction is situated 2 to 3 cm. in front of, and slightly below the tip of the coccyx; from this level, which in the male is opposite the apex of the prostate, the anal canal passes downwards and backwards from the lower end of the rectum, the backward bend of the gut at the anorectal junction being termed the *perineal flexure* of the rectum. In addition to its anteroposterior curve, the rectum deviates from the midline in the form of three lateral curves; the upper one is convex to the right, the middle one (which is the most prominent) bulges to the left, and the lower one is convex to the right; the beginning and end of the rectum are in the median plane.

The rectum is about 12 cm. long and its upper part has the same diameter as the sigmoid colon (about 4 cm. in the empty state), but its lower part is dilated to form the *rectal ampulla*. The rectum differs from the sigmoid colon in that it has no

sacculations, appendices epiploicæ or mesentery, while the tæniæ coli (p. 1447) blend about 5 cm. above the junction of the rectum and sigmoid colon to form two wide muscular bands which descend, one on the anterior and the other on the posterior wall of the rectum. The peritoneum is related only to the upper two-thirds of the rectum, covering at first its front and sides, but lower down its front only; from the latter it is reflected on to the bladder in the male, forming the rectovesical pouch of peritoneum, and on to the posterior wall of the vagina in the

FIG. 1200.—The rectum viewed from behind. Exposed by the removal of the lower part of the sacrum and the coccyx.

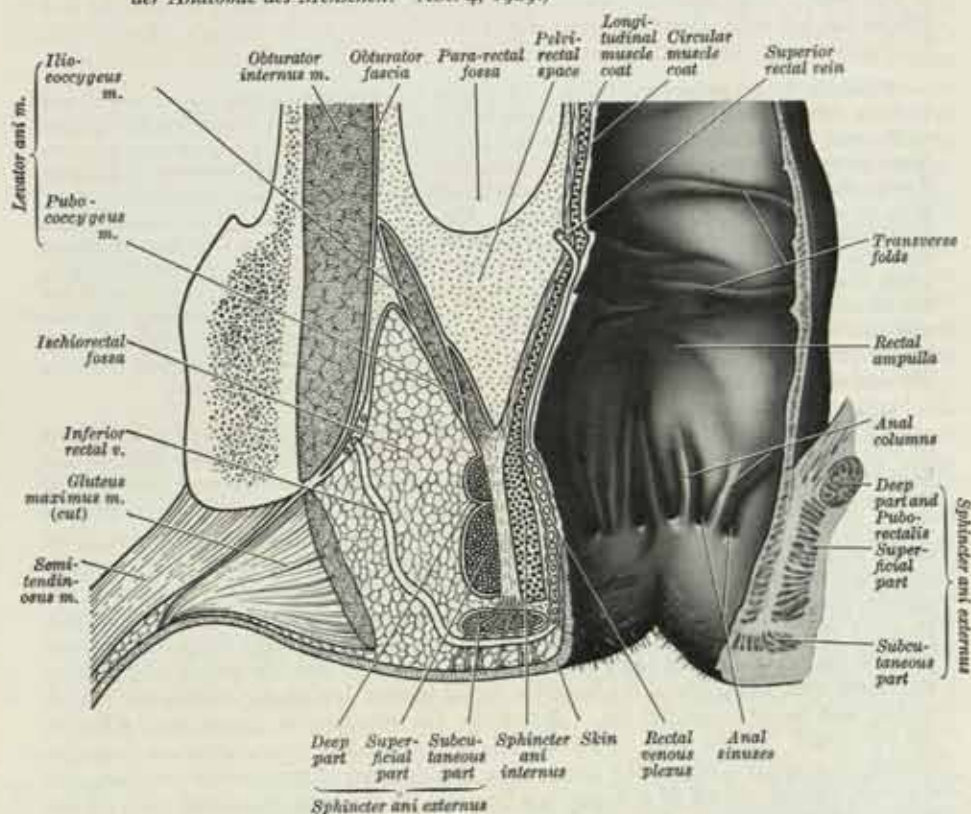


female, forming the recto-uterine pouch. The level of peritoneal reflection is higher in the male, the rectovesical pouch being about 7.5 cm. from the anus (the height to which the index finger inserted through the anus can reach); in the female the recto-uterine pouch is about 5.5 cm. from the anus. In the male foetus the peritoneum extends on the front of the rectum as far as the lower end of the prostate (p. 1505). On the sigmoid colon, as on the gut generally, the peritoneum is intimately attached to the muscle coat, but as it descends on the rectum, the peritoneum becomes more loosely attached and separated from the muscle by fatty tissue, to allow considerable expansion of this part of the gut.

In the empty state of the rectum, the mucous membrane of its lower part presents a number of longitudinal folds which are effaced by distension of the rectum. Besides these, there are permanent *transverse* or *horizontal folds* of a semi-lunar shape, which are most marked when the rectum is distended, and consist of an infolding of the mucous membrane and part of the circular muscle coat of the

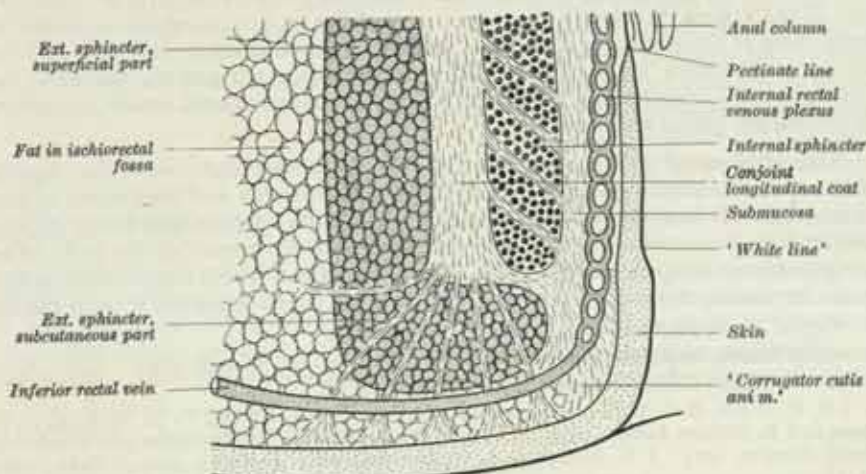
gut; the longitudinal muscular coat does not enter the folds. If well developed, the folds may cause some obstruction to the introduction of instruments into the rectum. Commonly three folds are present, but their number is variable. The

FIG. 1201.—Diagram of a coronal section of the rectum and anal canal and the structures adjoining. (Based partly on Rauber-Kopsch, *Lehrbuch und Atlas der Anatomie des Menschen*. Abt. 4, 1929.)



Note.—The internal pudendal vessels, the dorsal nerve of the penis and the perineal nerve are shown, cut, in the lateral wall of the ischiorectal fossa, imbedded in the 'lunette fascia'.

FIG. 1202.—A portion of fig. 1201, enlarged to show greater detail.



upper one is situated near the commencement of the rectum and may be on the left or the right side; occasionally it may encircle the gut and the lumen of the gut is then somewhat constricted at this site; the middle fold is the largest and most constant, and is situated immediately above the ampulla of the rectum; it projects from the anterior and right walls of the rectum just below the level at which the peritoneum is reflected from the anterior surface of the rectum; the circular muscle in this fold is more marked than in the others. The lowest fold is inconstant and lies on the left side, about 2.5 cm. below the middle fold; sometimes a fourth fold is present on the left side, about 2.5 cm. above the middle fold described above.

Paterson* considered the rectum to consist functionally of two parts, one above and the other below the middle fold, the upper part containing faeces and being free to distend towards the peritoneal cavity, while the lower part occupies a more confined situation, enclosed in a tube of condensed extraperitoneal tissue and (except during defaecation) empty in normal individuals, though in cases of chronic constipation, or after death, it may contain faeces. He also believed that the horizontal folds supported the weight of the faeces in the upper part of the rectum. It may be noted that the part of the rectum above the middle fold is developed from the hind gut, while the part below, together with the upper part of the anal canal, is derived from the cloaca (post-allantoic gut). O'Beirne† and Hurst‡ however, believed that the sigmoid colon acts as the faecal reservoir, that in normal individuals the rectum is empty (though it may contain faeces in cases of chronic constipation), and that the passage of faeces into the rectum normally excites the desire to defaecate.

Relations of the rectum.—*Posteriorly* the rectum is related in the median plane to the lower three sacral vertebrae, the coccyx, the median sacral vessels, the ganglion impar and branches of the superior rectal vessels, while on either side of the midline the following structures, particularly those of the left side, lie behind the rectum; namely, the Piriformis muscle, the anterior rami of the lower three sacral and coccygeal nerves, the sympathetic trunk, the lower lateral sacral vessels and the Coccygeus and the Levator ani muscles. The rectum is attached to the sacrum along the lines of the anterior sacral foramina by fibro-areolar tissue which encloses the sacral nerves, the pelvic splanchnic nerves passing from the anterior rami of the second, third (and fourth) sacral nerves to join the pelvic plexuses on the rectal wall, branches of the superior rectal vessels, lymphatic vessels and lymph nodes, and loose perirectal fat. *Anteriorly*, the relations of the rectum differ in the two sexes. In the male, above the site of reflection of the peritoneum from the rectum, the upper parts of the base of the bladder and of the seminal vesicles, and the rectovesical pouch of the peritoneum and its contents (terminal coils of the ileum and the sigmoid colon) lie in front of the rectum; while below the peritoneal reflection the rectum is related anteriorly to the lower parts of the base of the bladder and of the seminal vesicles, the deferent ducts, the terminal parts of the ureters and the prostate. In the female, above the peritoneal reflection, the uterus, the upper part of the vagina and the recto-uterine pouch of the peritoneum and its contents (terminal coils of the ileum and the sigmoid colon) lie in front of the rectum, while below the peritoneal reflection the rectum is related anteriorly to the lower part of the vagina. *Laterally*, the upper part of the rectum is related to the pararectal fossa of the peritoneum and its contents (sigmoid colon or lower part of the ileum), while below the peritoneal reflection the pelvic sympathetic plexuses, the Coccygei and Levatores ani, and branches of the superior rectal vessels constitute its immediate lateral relations.

The **anal canal** § (figs. 1201, 1202) begins where the lower end of the ampulla of the rectum suddenly narrows, and it passes downwards and backwards to end at the anus. It is about 3.8 cm. long in the adult, its anterior wall being slightly shorter than its posterior, and in the empty condition its lumen has the form of an anteroposterior longitudinal slit. Behind, it is in contact with a mass of fibrous and muscular tissue, termed the *anococcygeal ligament*, which separates it from the tip

* A. M. Paterson, *J. Anat. and Physiol.*, 1909, 4, 127.

† J. O'Beirne, *New views on the processes of defaecation, etc.*, Dublin, 1833.

‡ A. F. Hurst, *Chronic constipation*, London, 1919.

§ F. R. Wilde, *Brit. J. Surgery*, 1949, 36, 279; E. T. C. Milligan, C. N. Morgan, L. E. Jones and R. Officer, *Lancet*, 1937, 2, 1119; W. B. Gabriel, *The Principles and Practice of Rectal Surgery*, 1945; J. C. Goligher, A. G. Leacock and J.-J. Brossy, *Brit. J. Surg.*, 1955, 43, 51.

of the coccyx; in front, it is separated by the *perineal body* (p. 608) from the membranous part of the urethra and the bulb of the penis in the male, and from the lower end of the vagina in the female; laterally it is related to the ischio-rectal fossae. Over its whole length it is surrounded by sphincter muscles, the tone of which normally keeps the canal closed.

The lining of the canal differs in various parts. The mucous membrane of the lower part of the rectum is pale pink in colour and semitransparent, allowing the pattern of the branching radicles of the superior rectal vessels to be seen through it. The upper half (15 mm.) of the anal canal is also lined by mucous membrane and is plum-coloured owing to the blood in the subjacent internal rectal venous plexus. The epithelium in this region is variable in character; in some cases it is stratified columnar in type, in others it is mainly stratified squamous with patches of stratified columnar, and yet in others it contains areas of stratified columnar, stratified squamous, stratified polyhedral cells (the cells nearest the lumen being columnar), and a single layer of simple columnar cells like those lining the rectum.* In this part of the canal the mucous membrane presents six to ten vertical folds, the *anal columns*, which are well marked in the child but are sometimes not so well-defined in the adult. Each column contains a terminal radicle of the superior rectal artery and vein, these radicles being largest in the left-lateral, right-posterior and right-anterior quadrants of the wall of the anal canal; enlargements of the venous radicles in these three sites constitute primary internal hæmorrhoids. The lower ends of the columns are joined together by small crescentic valve-like folds of mucous membrane, the *anal valves*, above each of which lies a small recess or *anal sinus*. The sinuses, deepest on the posterior wall of the canal, may lodge foreign matter and become infected, leading to abscess formation in the wall of the anal canal; the anal valves may be torn by hard fæces, producing an anal fissure (p. 1446). The line along which the anal valves are situated is termed the *pectinate line*; it lies opposite the middle of the Sphincter ani internus and is commonly considered to be the site at which the anal membrane was situated in the early fœtus; thus it represents the place of junction of the entodermal part of the anal canal (developed from the cloaca) and the ectodermal part (derived from the anal pit or proctodæum). Sometimes small epithelial projections (anal papillæ) are present on the edges of the anal vales; they are considered to be remnants of the anal membrane. Johnson,† however, maintained that the junction of the ectodermal and entodermal parts of the anal canal is situated lower down. The succeeding part of the anal canal extends for about 15 mm. below the anal valves, and is known as the *transitional zone* or *pecten*. Its epithelium is stratified and is intermediate in thickness between the single layer of columnar epithelium lining the upper part of the canal and the skin lining the lower part; unlike the latter, it contains no sweat glands. The transitional zone also overlies the internal rectal venous plexus and in life has a shiny and bluish appearance. Its submucosa contains fairly dense connective tissue, in contrast with the lax connective tissue of the upper half of the anal canal, suggesting a firm support and anchorage of the lining of the pecten to the surrounding muscle coats of this part of the anal canal. The transitional zone ends below at a narrow wavy zone, commonly called the 'white line' (of Hilton); in the living subject this 'line' is bluish-pink in colour and is only rarely recognisable macroscopically.‡ Its importance lies in the fact that it is situated at the level of the interval between the subcutaneous part of the External sphincter and the lower border of the Internal sphincter, and on digital examination of the anal canal in the living subject a slight groove ('anal intersphincteric groove') can be felt at this site. Below the 'white line', the lower 8 mm. or so of the anal canal are lined by true skin which may be dull white or brownish in colour. There are considerable variations in the zones of epithelium described above and there is frequently an interpenetration of the various types of epithelia, so that the zones may not be rigidly separated from each other.

In the region of the anal sinuses, *anal glands* § extend upwards or downwards into the submucosa and occasionally even penetrate deeply into the Internal sphincter. Each gland consists of one to six spiral or straight tubules, which may

* E. W. Walls, personal communication.

† F. P. Johnson, *Amer. J. Anat.*, 1914, 16, 1.

‡ M. R. Ewing, *Proc. Roy. Soc. Med.*, 1954, 47, 525.

§ M. R. Hill, E. H. Sharyock and F. G. Rebell, *J. Amer. Med. Assoc.*, 1943, 121, 742.

be branched and which are lined by two or three layers of cells that are secretory in nature and contain mucin. The duct of each gland, which is lined by stratified columnar epithelium, opens into a small depression of the lining of the anal canal, called an *anal crypt*. The glands are surrounded by lymphocytes in a form resembling lymph follicles, and the submucosal plain muscle is very thick in their vicinity. Occasionally the terminal part of a duct is not canalized and, in these circumstances, the secretion may distend the gland to form a cyst. The glands are important clinically in that they may become infected with the result that an abscess or a fistula may be produced. The glands vary widely in number and in their depth of penetration, and they may even extend in the submucosa above the anorectal junction.

The **anus** or **anal orifice** is the lower aperture of the anal canal and is situated about 4 cm. below and in front of the tip of the coccyx, in the cleft between the buttocks. The pigmented skin around it is thrown into radiating folds which converge towards the orifice and are continued into the lower part of the anal canal. Hairs are developed in this skin after puberty, in the male only.

Musculature of the anal canal (fig. 1201). At the ano-rectal junction the unstriated circular muscle coat of the rectum becomes considerably thickened (5 to 8 mm.) to form the *Sphincter ani internus*. The sphincter surrounds the upper three-quarters (30 mm.) of the anal canal and ends below at the level of the 'white line'.

The **Sphincter ani externus** surrounds the whole length of the anal canal; it consists of three parts, each composed of striated muscle. The *subcutaneous part* of the External sphincter is a flat band, about 15 mm. broad, which surrounds the lower part of the anal canal and lies horizontally below the lower borders of the Internal sphincter and of the superficial part of the External sphincter; it lies beneath the skin at the anal orifice and, centrally, it lies beneath the anal canal skin at the 'white line'. The *superficial part* of the External sphincter is elliptical and lies deep to the subcutaneous part. It is the only part of the External sphincter that is attached to bone, arising from the posterior surface of the terminal piece of the coccyx by a median fibrous aponeurosis, the anococcygeal raphe; anteriorly, after surrounding the lower part of the Internal sphincter, it is inserted chiefly into the perineal body. The *deep part* of the External sphincter is a thick annular band which surrounds the upper part of the Internal sphincter; its deeper fibres are fused with and inseparable from those of the Puborectalis (p. 604). In front of the anal canal many of the fibres of the deep part of the External sphincter decussate and become continuous with the Superficial transverse perineal muscles, this arrangement being more marked in the female. Histological investigation* indicates that there is no clear separation of the three parts of the External sphincter from each other. The tone of the anal sphincters (Internal and External) keeps the anal canal and anus closed; during defaecation these muscles are relaxed and the lower part of the anal canal is opened out and flattened, so that the mucous membrane of the upper part of the canal appears at the surface. The External sphincter can be voluntarily contracted and thus more firmly occlude the anus. The nerve supply of the External sphincter is derived from the inferior rectal branch of the pudendal nerve (S. 2 and 3) and from the perineal branch of the fourth sacral nerve.

At the anorectal junction the Puborectalis fibres of the Levator ani fuse with the longitudinal muscle coat of the rectum to form a conjoint longitudinal coat for the anal canal, between the Internal and External sphincters (fig. 1201). Distally, this conjoint coat becomes increasingly fibro-elastic, and at the level of the 'white line' it breaks up into a number (9 to 12) of fibro-elastic septa which spread out fanwise through the subcutaneous part of the External sphincter to become attached to the dermis of the skin around the anus. These septa consist mainly of yellow elastic fibres and the most lateral septum passes between the subcutaneous and superficial parts of the External sphincter and becomes lost in the fat of the ischio-rectal fossa. Milligan and his co-workers (see footnote, p. 1442) maintained that the most medial septum passes between the Internal sphincter and the subcutaneous part of the External sphincter to reach the lining of the anal canal at the 'white line'; they called it the anal intermuscular septum and believed that it produces the groove referred to above as the 'anal intersphincteric groove'. Others,† however, point

* J. C. Goligher, A. G. Leacock and J.-J. Brossy, *Brit. J. Surg.*, 1955, 43, 51.

† E. W. Walls, Personal communication; J. C. Goligher, A. G. Leacock and J.-J. Brossy, *Brit. J. Surg.*, 1955, 43, 51; F. R. Wilde, *Brit. J. Surg.*, 1949, 36, 279.

out that the longitudinal fibres in this position, compared with those penetrating through the subcutaneous part of the External sphincter, are too weak and scanty to warrant the name of 'anal intermuscular septum', and Walls believes that the 'anal intersphincteric groove' is produced by the contraction of the subcutaneous part of the External sphincter in the living subject. In the submucosa of the anal canal below the level of the anal sinuses there is a well-marked layer composed of plain muscle, yellow elastic fibres and connective tissue. These fibres are derived mainly from strands of the conjoint longitudinal coat of the anal canal which pass inwards and downwards between bundles of the Internal sphincter (fig. 1202). Some of the strands end inferiorly by passing laterally around the lower edge of the Internal sphincter to join the main longitudinal coat. The majority, however, continue downwards and laterally, superficial to the subcutaneous part of the External sphincter, to be attached to the dermis of the skin from the level of the 'white line' to well beyond the anus. These fibres produce the corrugation of the skin characteristic of this region and constitute the 'Corrugator cutis ani muscle'. Wilde maintains that these fibres are exclusively yellow elastic fibres, though Goligher and his colleagues have noted the presence of plain muscle fibres among them. Between the subcutaneous External sphincter and the skin of the anal canal lies the external rectal venous plexus; communicating veins pass between the external and internal rectal plexuses and thus establish connections between the portal and systemic venous systems. The radiating elastic septa end below by breaking up into a network which subdivides the narrow interval between the subcutaneous External sphincter and the skin into a compact honeycomb; this arrangement accounts for the severe pain produced by collections of pus or blood which may occur in this region and for the localisation of a hæmorrhage following the rupture of a vein of the external rectal plexus. The submucosa above the 'white line', containing the internal rectal venous plexus, is known surgically as the 'submucous space', while that below the 'white line', containing the external rectal plexus is called the 'perianal space'. These two 'spaces' are separated by the dense submucous layer of plain muscle and connective tissue referred to above, which is especially well-marked for a short distance below the anal valves (E. W. Walls, personal communication).

At the anorectal junction the Puborectalis, deep External sphincter and Internal sphincter collectively form the 'anorectal ring' of muscle, which can be felt by a finger in the anal canal; *surgically, division of the ring results in rectal incontinence*. The anterior part of the ring is not so well marked, since relatively few fibres of the Puborectalis pass in front of the anorectal junction, most of the fibres of this muscle forming a sling which loops round the sides and back of the gut at this site, slinging the anorectal junction forwards towards the pubis.

Correlated with the dual development of the anal canal, the part above the anal valves being derived from the entodermal cloaca and the part below from the ectodermal proctodæum (p. 195), the following facts may be noted. In the ectodermal part, the lining is skin which is supplied by spinal nerves (inferior rectal nerve), the arterial blood supply is from the inferior rectal artery, the venous drainage is by the inferior rectal vein which passes to the internal pudendal vein (a systemic vein), and the lymphatics drain with those of the perianal skin into the superficial inguinal lymph nodes. In the entodermal part, the epithelium is simple columnar, the mucous membrane is supplied by sympathetic nerves, the arterial blood supply is (mainly) from the superior rectal artery, the venous drainage is by the superior rectal vein which continues as the inferior mesenteric vein (a tributary of the portal venous system), and the lymphatics drain with those of the rectum (p. 902). In cases of obstruction of the portal venous system, the collateral circulation opened up by the anastomosis between the portal and systemic veins in the anal canal may result in the dilatation of these veins. The different nerve supply of the two parts is correlated with a response to different types of stimuli; the lower part is very sensitive and responds to touch, pain and thermal stimuli like skin in general; the upper part, like the gut, has a high threshold for the above stimuli and responds more readily to increase in tension. The effects of the difference in the innervation of the two parts of the anal canal are seen in cases of piles (varicosities of the veins in the anal canal) which may be covered with skin in their lower parts and mucous membrane in their upper parts; in injection of such piles with a view to their thrombosis, the needle is inserted into the insensitive upper part and

not into the very sensitive skin-covered part. Fissure in ano (tearing of the anal valves) is very painful as it involves the lower sensitive part of the anal canal.

Rectal examination.—On inserting the index finger through the anal orifice, it is first grasped by the subcutaneous part of the External sphincter, and then, higher up in the anal canal, by the Internal sphincter, the superficial and deep parts of the External sphincter and the Puborectalis; beyond this, it may reach the lowest (or even the middle) transverse rectal fold. Many of the structures related to the anal canal and lower part of the rectum may be felt through the walls of these parts of the gut. In the male, through the anterior wall, the bulb of the penis and (particularly if a catheter is placed in the urethra) the membranous part of the urethra are first identified, and then, about 4 cm. above the anus, the prostate can be felt; beyond this the seminal vesicles, if enlarged, and the base of the bladder (especially if the viscus is distended) may be recognised. Posteriorly, the pelvic surfaces of the lower part of the sacrum and the coccyx may be palpated. Laterally, the ischial spine, ischial tuberosity and, if enlarged, the internal iliac lymph nodes may be felt. Pathological thickening of the ureters, swellings in the ischio-rectal fossæ and abnormal contents of the rectovesical peritoneal pouch may also be detected. In the female, the uterine cervix can be palpated through the anterior wall of the rectum (and, for example, its degree of dilatation during child-birth determined), and pathological conditions of the ovaries, uterine tubes, broad ligaments and recto-uterine pouch may be detected. In both sexes tenderness of an inflamed vermiform appendix can be elicited, particularly if that organ occupies a pelvic position.

Various parts of the pelvic fascia are considered from the surgical point of view to be 'fascial supports' of the rectum, which must be divided to mobilise the rectum. From the anterior surface of the lower part of the sacrum a stout avascular condensation of fascia passes forwards to the posterior aspect of the anorectal junction; it is known as 'the fascia of Waldeyer'. The fascia around the middle rectal vessels passes from the posterolateral wall of the pelvis (at the level of the third sacral vertebra) to the rectum, constituting on each side 'the lateral ligament of the rectum'. Anteriorly the fascia between the rectum and the seminal vesicles and prostate (the rectovesical fascia, p. 1505) is more loosely attached to the latter structures than to the rectum, and in surgical excision of the rectum this fascia is separated along the plane between it and the prostate and seminal vesicles.

In addition to the ischio-rectal fossæ (p. 606), the following 'spaces' of surgical importance are described in relation to the rectum and anal canal. The pelvirectal space comprises the loose extraperitoneal connective tissue above the Levator ani; it is divided into anterior and posterior regions by the 'lateral ligaments of the rectum'. The submucous space of the anal canal lies between the mucous membrane of the canal (above the 'white line') and the Internal sphincter, and contains the internal rectal venous plexus and lymphatics; above, it is continuous with the submucosa of the rectum. The perianal space surrounds the anal canal below the 'white line' (see p. 1445); its lateral part is bounded above by the most lateral of the radiating elastic septa that pass through the subcutaneous External sphincter; the latter septum divides the ischio-rectal fossa into an upper main space containing coarsely lobulated fat and a lower perianal space which contains finer and more compact fat. The perianal space contains the subcutaneous External sphincter, the external rectal venous plexus and the terminal branches of the inferior rectal vessels and nerves. Owing to the arrangement of the radiating septa passing through the subcutaneous External sphincter, pus in the perianal space tends to spread to the anal canal at the 'white line' or to the surface of the perianal skin rather than to the main part of the ischio-rectal fossa. Since the perianal space surrounds the lower part of the anal canal, pus on one side may spread round the canal in the space.

Structure of the large intestine.—The large intestine has four coats: serous, muscular, submucous and mucous.

The *serous coat* is the peritoneum, which invests the different portions of the large intestine to a variable extent (*vide ante*). In the course of the colon the peritoneal coat is thrown into a number of small pouches filled with fat, called *appendices epiploicæ*. They are most numerous on the transverse colon and the sigmoid colon; they are not present on the rectum.

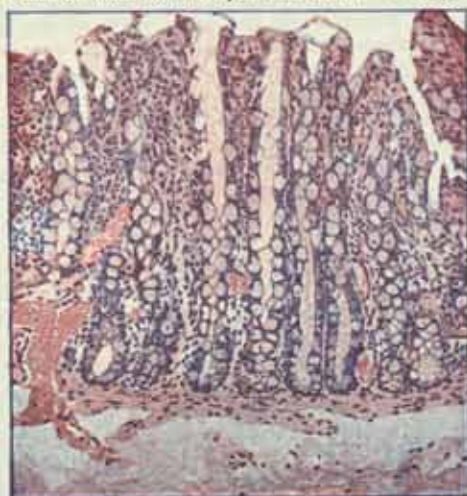
The *muscular coat* consists of an external longitudinal, and an internal circular layer of unstriped muscular fibres.

The *longitudinal fibres* form a continuous layer over the surface of the large intestine,* but in certain situations this layer is thickened to form conspicuous longi-

* G. F. Hamilton, *J. Anat.*, 80, Proc., p. 230, 1946.

tudinal bands, termed *tæniæ coli*, and in the intervals between them the longitudinal coat is less than half the thickness of the circular coat. In the cæcum and colon three *tæniæ* are present, ranging from 6 to 12 mm. in width in different individuals. One (the *tænia libera*) is placed anteriorly in the cæcum, ascending, descending and sigmoid colon, but is placed inferiorly on the transverse colon; the second (the *tænia mesocolica*) is situated on the posteromedial surface of the cæcum, ascending, descending and sigmoid colon, but posteriorly on the transverse colon, at the site of attachment of the transverse mesocolon; the third (the *tænia omentalis*) is placed posterolaterally in the cæcum, ascending, descending and sigmoid colon, but is situated on the antero-superior surface of the transverse colon, at the site where the posterior (ascending) layers of the greater omentum meet this part of the large intestine. These bands are shorter than the other coats of the intestine, and serve to produce the sacculi or haustrations which are characteristic of the cæcum and colon; accordingly, when they are dissected off, the tube can be lengthened, and its sacculated character becomes lost. In the descending colon the *tæniæ* increase in thickness at the expense of the rest of the longitudinal coat and on the sigmoid colon this coat undergoes a real increase in its total bulk. In the sigmoid colon the longitudinal fibres become more scattered; and round the rectum they spread out and form a layer, which completely encircles this portion of the gut, but is thicker on the anterior and posterior surfaces, so that an anterior and a posterior broad band can be recognised. At the rectal ampulla, a few strands of the anterior longitudinal fibres pass forwards to the perineal body (fig. 608); they constitute the *Recto-urethralis muscle*. In addition, two fasciculi of

FIG. 1203.—A section through the mucous membrane of the large intestine (cat). Stained with hæmatoxylin and eosin. $\times 100$.



Note the presence of large numbers of goblet cells and the vascularity of the mucosa.

plain muscular tissue arise from the front of the second and third coccygeal vertebrae, and pass downwards and forwards to blend with the longitudinal muscular fibres on the posterior wall of the anal canal. These are known as the *Rectococcygeal muscles*.

The *circular fibres* form a thin layer over the cæcum and colon, being especially accumulated in the intervals between the sacculi; in the rectum they form a thick layer, and in the anal canal they become numerous, and constitute the *Sphincter ani internus*.

The *submucous coat* connects the muscular and mucous layers closely together.

The *mucous membrane* of the cæcum and colon is pale, smooth, destitute of villi, and raised into numerous crescentic folds which correspond with the intervals between the sacculi; that of the rectum is thicker, of a darker colour, more vascular and connected more loosely with the muscular coat.

As in the small intestine, the mucous membrane consists of a muscular layer [*lamina muscularis mucosæ*]; a quantity of retiform tissue in which the vessels ramify; a basement-membrane, and an epithelium which is of the columnar variety and resembles the epithelium found in the small intestine. It contains glands and solitary lymphatic follicles.

The *glands* of the large intestine are minute tubular prolongations of the mucous membrane arranged perpendicularly to its surface; they are longer, more numerous, and placed in much closer apposition than those of the small intestine; and they open by minute rounded orifices upon the surface, giving it a cribriform appearance. Each gland is lined with short columnar epithelium, the majority of the cells being goblet-cells (fig. 1203).

The *solitary lymphatic follicles* of the large intestine are most abundant in the cæcum and vermiform appendix, but are irregularly scattered over the rest of the large intestine also. They are similar to those of the small intestine.

The structure of the vermiform appendix is described on p. 1436.

Vessels and Nerves.—The arteries which supply the part of the large intestine developed from the mid-gut (cæcum, appendix, ascending colon, right two-thirds of transverse colon) are derived from the colic branches of the superior mesenteric artery; those supplying the left part of the transverse colon, descending colon, sigmoid colon, rectum and upper half of the anal canal (hind-gut derivatives) are the inferior mesenteric artery (and its terminal branch, the superior rectal) and the middle rectal artery. They give off large branches, which ramify between and supply the muscular coats, and after dividing into small vessels in the submucous tissue pass to the mucous membrane. The arteries of the rectum and anal canal are the superior rectal artery (the continuation of the inferior mesenteric), which is the chief artery of the rectum and which divides into two branches that run down, one on each side of the rectum, and break up into terminal branches that pierce the muscular coat and pass in the submucosa of the rectum and thence in the anal columns as far as the anal valves, where they form looped anastomoses; the middle rectal arteries, which run in the 'lateral ligaments of the rectum' to supply the muscle coats of the lower part of the rectum and anastomose with each other but only form poor anastomoses with the superior and inferior rectal arteries; the inferior rectal arteries, which supply the Internal and External sphincters, the anal canal below the anal valves, and the perianal skin; and the median sacral artery, which supplies the posterior wall of the anorectal junction and of the anal canal. The veins of the large intestine are the superior and inferior mesenteric veins, which drain the same parts of the large intestine as are supplied by the corresponding arteries. The veins of the rectum and anal canal are the superior rectal veins, which commence from the internal rectal plexus in the anal canal and pass up in the rectal submucosa in the form of about six vessels of considerable size, to pierce the muscular wall of the rectum about 7.5 cm. above the anus and unite to form a single trunk, the superior rectal vein, which is continued as the inferior mesenteric vein; the middle rectal veins, which begin in the submucosa of the rectal ampulla and drain chiefly the muscular walls of this part of the rectum; and the inferior rectal veins, which begin from the external rectal plexus and drain the lower part of the anal canal.

The *nerve-supply* of the large intestine (exclusive of the lower half of the anal canal) is derived from the sympathetic and parasympathetic systems. The cæcum, appendix, ascending colon and the right two-thirds of the transverse colon (all derivatives of the mid-gut) have their sympathetic supply from the coeliac and superior mesenteric ganglia, and their parasympathetic supply from the vagus; in each case the nerves are distributed to the gut in the plexuses around the branches of the superior mesenteric artery. The left third of the transverse colon, descending colon, sigmoid colon, rectum and upper half of the anal canal (derivatives of the hind gut) derive their sympathetic supply from the lumbar part of the trunk and the superior hypogastric plexus by means of the plexuses on the branches of the inferior mesenteric artery. The parasympathetic supply to this part of the gut is derived from the pelvic splanchnic nerves (*nervi erigentes*). From these latter, fibres pass to the inferior hypogastric plexuses to supply the rectum and upper half of the anal canal; in addition, some fibres pass up uninterruptedly through the superior hypogastric plexus to be distributed along the inferior mesenteric artery to the transverse, descending and sigmoid colon (p. 1220). Further, branches from the pelvic splanchnic nerves pass up on the posterior abdominal wall behind the peritoneum, independently of the inferior mesenteric artery, to be distributed directly to the left colic flexure and descending colon (G. A. G. Mitchell, 1935, *Edin. Med. Journ.*, 42, 11). The ultimate distribution in the gut wall is similar to that in the wall of the small intestine (p. 1432). The sympathetic nerves to the rectum and upper part of the anal canal pass mainly along the inferior mesenteric and superior rectal arteries and partly via the superior and inferior hypogastric plexuses, the latter supplying the lower part of the rectum and the Internal sphincter. The parasympathetic supply from the pelvic splanchnic nerves passes forwards as long strands (about 3 cm. long) from the sacral nerves to join the inferior hypogastric plexuses on the sides of the rectum, being motor to the musculature of the rectum and inhibitory to the Internal sphincter. In surgical excision of the rectum, the dissection is kept close to the rectal wall, otherwise these nerves may be damaged with consequent dysfunction of the bladder, and, in the male, impotence resulting from failure of erection of the penis. Afferent impulses underlying sensations of physiological distension are conveyed by the parasympathetic nerves, while pain impulses are conducted by both the sympathetic and parasympathetic nerves supplying the rectum and upper part of the anal canal.

The *lymph nodes and vessels* of the large intestine are described on pp. 902-904.

Applied Anatomy.—The infrequency of rupture of the small intestine by external injury to the abdominal wall is attributable to its elasticity and the ease with which the coils glide over each other; the more fixed duodenum, particularly its third part as it crosses the vertebral column, is more liable to such damage.

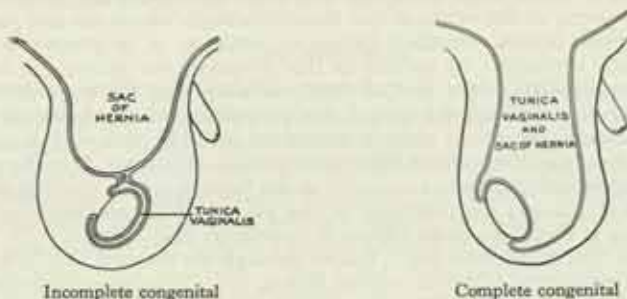
In external hernia the ileum is the portion of bowel most frequently herniated. When a part of the large intestine is involved it is usually the cæcum or the sigmoid colon.

Hernia.—The chief sites at which external hernia may occur are the inguinal region, the femoral canal, and the umbilical region.

Inguinal hernia.—In this form, the viscus is protruded through the inguinal region of the abdominal wall. The two principal varieties are oblique, and direct.

In *oblique inguinal hernia* the intestine is protruded through the lateral inguinal fossa (which lies behind the deep inguinal ring). Here the herniated gut pushes before it a pouch of the parietal peritoneum and extraperitoneal areolar tissue. It enters the inguinal canal at the deep inguinal ring and becomes invested by the internal spermatic fascia which encloses the constituents of the spermatic cord. In passing along the canal it displaces upwards the arched fibres of the Transversus and Obliquus internus, receives a covering from the cremasteric fascia and muscle, and lies in front of the constituents of the spermatic cord. It escapes from the canal at the superficial inguinal ring and here becomes invested by the external spermatic fascia. Lastly, it descends into the scrotum, here receiving additional coverings from the superficial fascia and the skin. Such a herniated part of the gut may become constricted at the deep inguinal ring, with consequent interference with its blood-supply (*strangulation*). In relieving the strangulation, the deep inguinal ring should be cut in an upward and

FIG. 1204.—The varieties of oblique inguinal hernia.



lateral direction to avoid the inferior epigastric vessels. In most cases, the occurrence of oblique inguinal hernia depends upon congenital defects in the processus vaginalis, the peritoneal pouch which precedes the descent of the testis (p. 214). Obliteration of the processus vaginalis may be complete at birth (G. A. G. Mitchell, *J. Anat.*, 1939, 78), or it may begin shortly before birth and be completed subsequently; the closure occurs first at the deep inguinal ring and at the top of the epididymis and gradually extends until the whole of the intervening portion is converted into a fibrous cord. Complete or partial failure of closure of the processus may occur, with consequent variations in the relation of the hernial protrusion to the testis and tunica vaginalis; e.g. where the processus is patent throughout, the herniated gut descends in front of the testis into the tunica vaginalis (complete congenital hernia), the processus and tunica vaginalis constituting the sac of the hernia. In incomplete congenital hernia (or hernia into the funicular process), the gut descends as far as the top of the testis, where the processus is sealed off from the tunica vaginalis (fig. 1204). Although the above types of inguinal hernia are called congenital, the actual occurrence of the hernia into the pre-existing peritoneal sac may not take place until adult life and then be produced by such factors as increased intra-abdominal pressure or sudden muscular strain.

In *direct inguinal hernia* the protrusion makes its way through some part of the inguinal triangle, either through (a) the lateral part, the medial inguinal fossa, where only extraperitoneal tissue and transversalis fascia intervene between the peritoneum and the aponeurosis of the Obliquus externus; or through (b) the supravesical fossa and the conjoint tendon, which stretches across the medial two-thirds of the triangle between the inferior epigastric artery and the median plane. In the former the hernial protrusion escapes from the abdomen on the lateral side of the conjoint tendon, pushes before it the peritoneum, extraperitoneal tissue and transversalis fascia, and enters the inguinal canal. It passes along nearly the whole length of the canal and finally emerges from the superficial ring, receiving an investment from the external spermatic fascia. The coverings of this form of hernia are similar to those of the oblique form, except

that a portion derived from the general layer of transversalis fascia replaces the internal spermatic fascia so that the hernia lies between the innermost and the middle covering of the spermatic cord.

In the second form, which is the more frequent, the hernia is either forced through the fibres of the conjoint tendon, or the tendon is gradually distended in front of it so as to form a complete investment for it. The intestine then enters the lower end of the inguinal canal, escapes at the superficial ring, lying on the medial side of the cord, and receives additional coverings from the external spermatic fascia, the superficial fascia and the skin. The coverings of this form therefore differ from those of the oblique form in that the conjoint tendon is substituted for the Cremaster, and the internal spermatic fascia is replaced by a portion of the general layer of the transversalis fascia. It may be observed that in all the varieties of inguinal hernia the most superficial covering is an investment from the external spermatic fascia and is identical with the outermost covering of the spermatic cord. An oblique inguinal hernia lies within the spermatic cord and shares all its coverings, but the covering which a direct hernia acquires from the transversalis fascia is distinct from the covering which the spermatic cord receives from that layer.

Direct inguinal hernia is of much less frequent occurrence than oblique, and is found more often in men than in women. The main differences in position between it and the oblique form are : (a) it is placed over the os pubis and not in the course of the inguinal canal ; (b) the inferior epigastric artery runs on the lateral side of the neck of the sac ; and (c) the spermatic cord lies along its lateral and posterior sides, not directly behind it as in oblique inguinal hernia. A direct hernia is always of the acquired variety.

The seat of stricture in both varieties of direct hernia is usually found either at the neck of the sac or at the superficial ring. In that form which perforates the conjoint tendon it may occur at the edges of the fissure through which the gut passes. In all cases of inguinal hernia, whether direct or oblique, it is proper to divide the stricture directly upwards : by cutting in this direction the incision is made parallel to the inferior epigastric artery, and all chance of wounding the vessel is thus avoided.

Femoral hernia.—In femoral hernia the protrusion of the intestine takes place through the femoral ring. As already described (p. 818), this ring is closed by the femoral septum, a partition of modified extraperitoneal tissue ; it is therefore a weak spot in the abdominal wall, and especially in the female, where the ring is larger, and where profound changes are produced in the tissues of the abdomen by pregnancy. Femoral hernia is therefore more common in women than in men.

When a portion of the intestine is forced through the femoral ring, it carries before it a pouch of peritoneum which forms the hernial sac. It receives an investment from the extraperitoneal tissue or femoral septum, and descends along the femoral canal as far as the saphenous opening ; at this point it changes its course, being prevented from extending farther down the sheath on account of the narrowing of the latter, and its close contact with the vessels, and also the close attachment of the superficial fascia and femoral sheath to the lower part of the circumference of the saphenous opening. The hernia is consequently directed forwards, pushing before it the cribriform fascia, and then curves upwards over the inguinal ligament and the lower part of the aponeurosis of the Obliquus externus. While the hernia is contained in the femoral canal it is usually of small size, owing to the resisting nature of the surrounding parts, but when it escapes from the saphenous opening into the loose areolar tissue of the groin it becomes considerably enlarged. The direction taken by a femoral hernia is at first downwards, then forwards and upwards ; in the application of taxis for the reduction of a femoral hernia, therefore, pressure should be directed in the reverse order, and the thighs should be passively flexed in order that the greatest degree of relaxation may be obtained.

The coverings of a femoral hernia from within outwards are : peritoneum, femoral septum, femoral sheath, cribriform fascia, superficial fascia and skin. Astley Cooper described an investment for femoral hernia under the name of *fascia propria*, lying immediately external to the peritoneal sac but frequently separated from it by some adipose tissue. Surgically it is important to remember the frequent existence of this layer on account of the ease with which an inexperienced operator may mistake the fascia for the peritoneal sac and the contained extraperitoneal fat for omentum, as there is often a great excess of subperitoneal fatty tissue enclosed in the '*fascia propria*'. In many cases it resembles a fatty tumour, but on further dissection the true hernial sac will be found in the centre of the mass of fat. The fascia propria is merely a modified femoral septum which has been thickened to form a membranous sheet by the pressure of the hernia.

When the intestine descends along the femoral canal only as far as the saphenous opening the condition is known as *incomplete* femoral hernia, in contradistinction to the *complete* hernia, which has passed through the opening. The small size of the protrusion in the incomplete form of hernia renders it an exceedingly dangerous variety

of the disease, from the extreme difficulty of detecting the existence of the swelling, especially in corpulent subjects.

The site of strangulation of a femoral hernia varies: it may be at the neck of the hernial sac; in the greater number of cases it is at the point of junction of the falciform margin of the saphenous opening with the free edge of the pectineal part of the inguinal ligament, or it may be at the margin of the saphenous opening. The stricture should in every case be divided in a direction upwards and medially for a distance of about 4 mm. to 6 mm. All vessels or other structures of importance in relation to the neck of the sac will thus be avoided.

The pubic tubercle forms an important landmark in serving to differentiate the inguinal from the femoral variety of hernia. The neck of the inguinal protrusion is above and medial to the tubercle, while the neck of the femoral protrusion is below and lateral to it.

Umbilical hernia.—Three varieties occur.

(a) *Congenital umbilical hernia.*—This variety is due to a failure of retraction of the umbilical loop of gut (p. 190).

(b) *Infantile umbilical hernia.*—This is due to stretching of the scar tissue in the umbilical region. It occurs usually within the first three years after birth and is associated with conditions causing increased intra-abdominal pressure.

(c) *Acquired umbilical hernia.*—This variety really occurs through the linea alba, usually immediately above the umbilicus (para-umbilical hernia), and most frequently occurs in obese multiparous females.

Rarely, hernia may occur at other sites, e.g. through the lumbar triangle (p. 613), the obturator foramen, the greater or lesser sciatic foramen, or the ischiorectal fossa. Sometimes hernia may occur at the site of a scar following an abdominal operation (incisional hernia), particularly if the wound becomes septic.

THE PANCREAS

The **pancreas** is a soft, lobulated, greyish-pink gland extending nearly transversely across the posterior abdominal wall, behind the stomach, from the duodenum to the spleen. It is flattened and elongated, measuring from 12 cm. to 15 cm. long. Its broad, right extremity is called the *head*, and is connected to the main portion, or *body*, by a slightly constricted *neck*; its narrow, left extremity forms the *tail*. It passes obliquely to the left and slightly upwards, across the posterior wall of the abdomen, at the back of the epigastric and left hypochondriac regions.

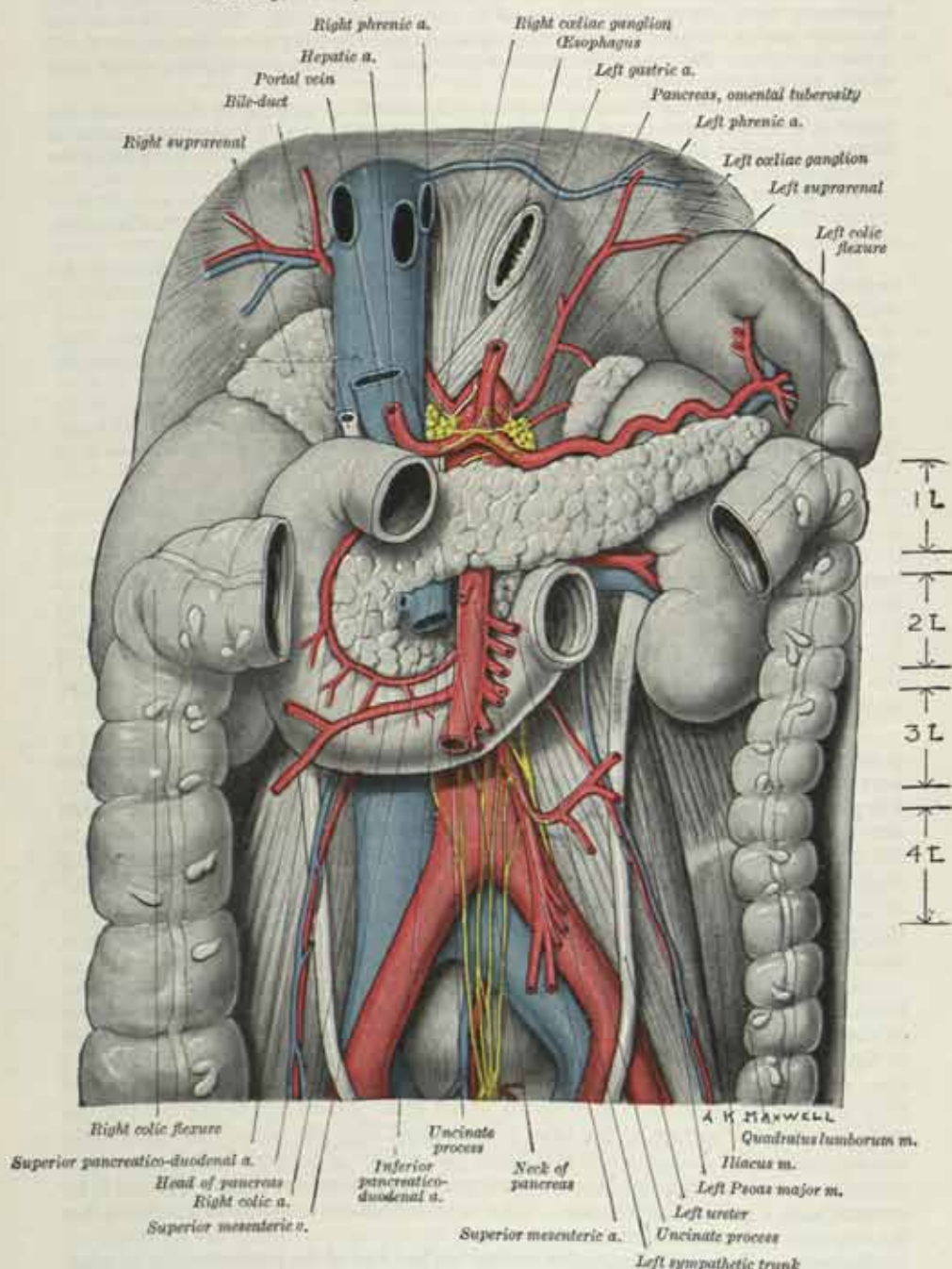
Relations (figs. 1205 to 1207).—The **head**, flattened from before backwards, is lodged within the curve of the duodenum. Its upper border is overlapped by the first part of the duodenum; the other borders are grooved to receive the adjacent margin of the duodenum, which they overlap in front and behind to a variable extent. Sometimes a small part of the head of the pancreas is actually embedded in the wall of the second part of the duodenum. From the lower and left part of the head there is a prolongation named the *uncinate process*, which projects upwards and to the left behind the superior mesenteric vessels. In or near the groove between the duodenum and the right lateral and lower borders of the head are the anastomosing superior and inferior pancreaticoduodenal arteries (pp. 798, 802).

Anterior surface.—From the upper part of the front of the head of the pancreas, the neck juts forwards, upwards and towards the left, to be continued into the body of the pancreas. The boundary between the head and neck, on the right side (and in front), is a groove for the gastroduodenal artery; on the left side (and behind) a deep notch intervenes between the head and the neck, and in it the superior mesenteric and splenic veins unite to form the portal vein. Below and to the right of the neck the anterior surface of the head is in contact with the transverse colon, only areolar tissue intervening, while still lower the surface is covered with peritoneum continuous with the inferior layer of the transverse mesocolon (fig. 1167), and is in contact with a coil of the jejunum. The uncinate process is crossed anteriorly by the superior mesenteric vessels.

Posterior surface.—The posterior surface of the head of the pancreas is in relation with the inferior vena cava, which runs upwards behind it and covers nearly the whole of this aspect. In addition, it is related to the terminal parts of the renal veins and the right crus of the Diaphragm. The uncinate process passes in front of the aorta. The bile-duct lies either in a groove on the upper and lateral part of the posterior surface of the head of the pancreas or in a canal in its substance (McConnell *).

The **neck**, about 2 cm. long, is confluent below and to the right with the anterior surface of the head; it extends forwards, upwards and to the left, and

FIG. 1205.—The pancreas and duodenum. Anterior aspect.



The right and left hepatic veins have been cut away at their points of entry into the inferior vena cava.

The superior hypogastric plexus is shown in front of the sacral promontory and the sympathetic nerves which form it are seen descending across the bifurcation of the aorta, the left common iliac vein and the body of the fifth lumbar vertebra.

merges imperceptibly into the body. Its anterior surface is covered with peritoneum and supports the pylorus, a portion of the omental bursa intervening; the gastro-

duodenal and the superior pancreaticoduodenal arteries descend in front of the gland at the right side of the junction of the neck with the head; its posterior surface is in relation with the superior mesenteric vein and the beginning of the portal vein.

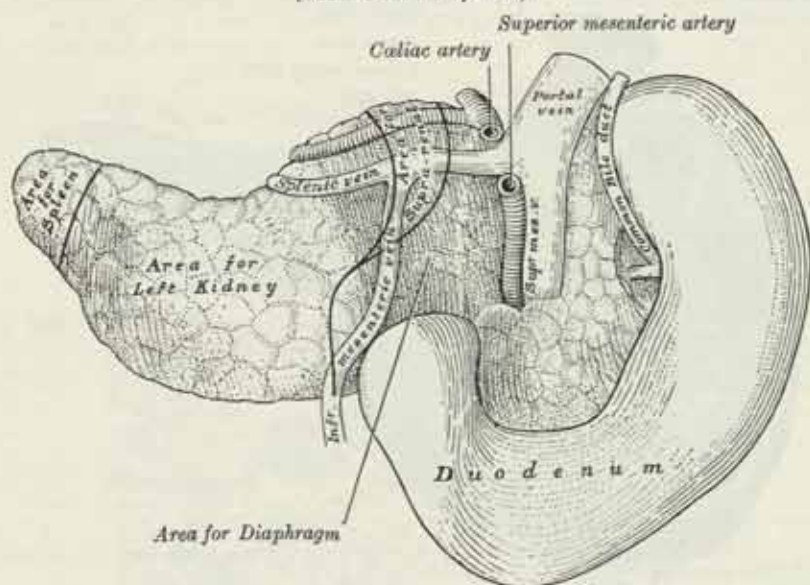
The **body** is somewhat prismoid in shape, and has three surfaces: anterior, posterior and inferior.

The *anterior surface* is concave, and is directed forwards and upwards; it is covered with peritoneum and is separated from the stomach by the omental bursa.

The *posterior surface* is devoid of peritoneum, and is in contact with the aorta and the origin of the superior mesenteric artery, the left crus of the Diaphragm, the left suprarenal gland and the left kidney and its vessels, particularly the left renal vein. It is intimately related to the splenic vein, which courses from left to right and separates it from the structures mentioned. The left kidney is also separated from the pancreas by the perirenal fascia and fat.

The *inferior surface* is narrow on the right but broader on the left, and is covered with peritoneum derived from the lower layer of the transverse mesocolon; it lies

FIG. 1206.—The pancreas and duodenum. Posterior surface.
(From a model by His.)



upon the duodenojejunal flexure and on some coils of the jejunum; its left extremity rests on the left colic flexure.

The *superior border* is blunt and flat to the right; narrow and sharp to the left, near the tail. A process, termed the *omental tuberosity*, usually projects from the right end of the superior border above the level of the lesser curvature of the stomach, and is in contact with the posterior surface of the lesser omentum. It is in relation above with the celiac artery, from which the hepatic artery courses to the right just above the gland, while the splenic artery runs towards the left following a wavy course along this border.

The *anterior border* separates the anterior from the inferior surface, and along this border the two layers of the transverse mesocolon diverge from each other: one passing upwards over the anterior surface, the other backwards over the inferior surface.

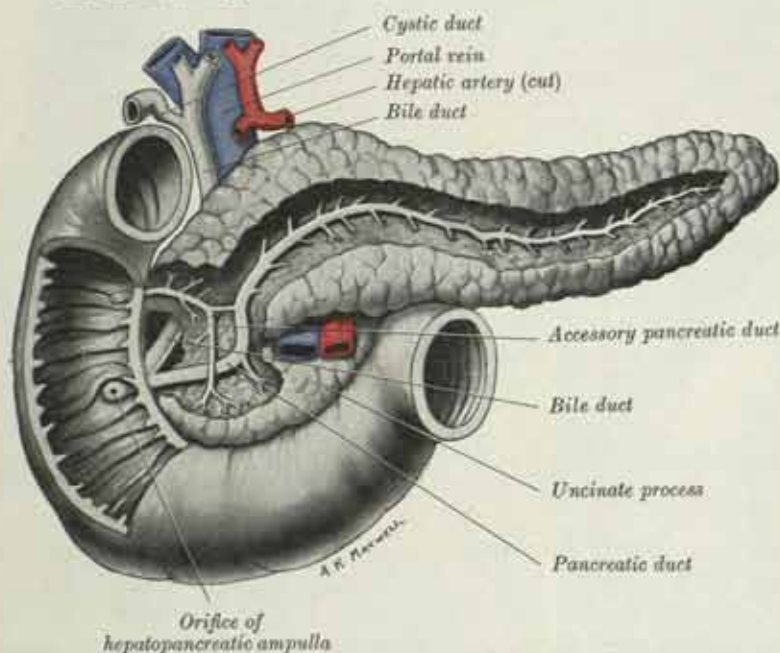
The *inferior border* separates the posterior from the inferior surface: the superior mesenteric vessels emerge under its right extremity.

The **tail** is narrow, and usually lies in contact with the inferior part of the gastric surface of the spleen. It is contained within the two layers of the lienorenal ligament together with the splenic vessels, to which it is closely related.

The **pancreatic duct** traverses the pancreas from left to right, lying nearer its posterior than its anterior surface (fig. 1207). It begins by the junction of the small

ducts of the lobules situated in the tail of the pancreas, and, running from left to right through the body, receives the ducts of the various lobules composing the gland, the latter joining the main duct almost at right angles ('herring-bone pattern'). Considerably augmented in size, it reaches the neck of the pancreas, and turning downwards, backwards, and to the right, comes into relation with the bile-duct, which lies to its right side. Together the two ducts pass obliquely into the wall of the second part of the duodenum, and there unite to form a short dilated duct, named the *hepatopancreatic ampulla* (or ampulla of the bile-duct) (see p. 1466). The constricted distal end of this ampulla opens on the summit of the major duodenal papilla, which is situated within this part of the duodenum at the junction of its medial and posterior walls, from 8 cm. to 10 cm. distal to the pylorus. As a rule the two ducts do not unite until they approach very close to the opening on the major duodenal papilla. The pancreatic duct, near the duodenum, is about the size of an ordinary quill. Sometimes the pancreatic duct and the bile-duct open separately into the duodenum. Frequently there is an additional duct, which

FIG. 1207.—Dissection of pancreas and duodenum to expose the pancreatic duct and the accessory pancreatic duct, and the connexion between them.



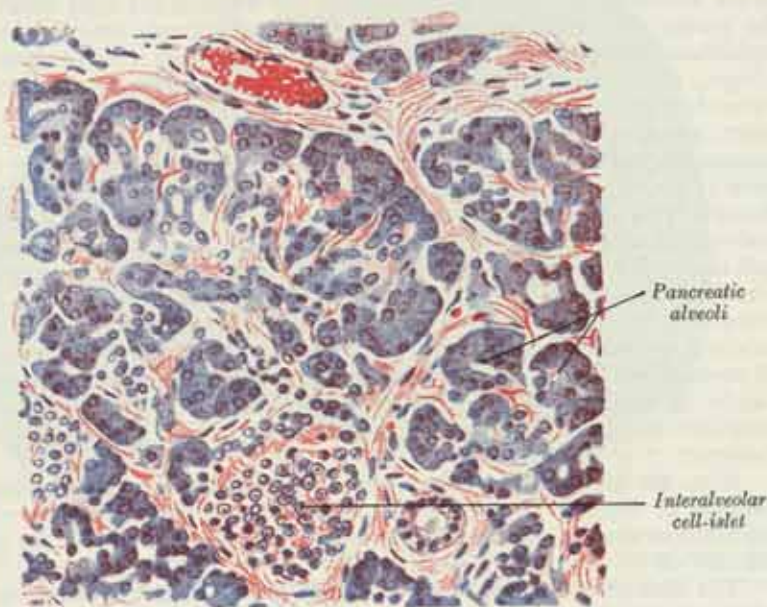
receives the ducts from the lower part of the head, and is known as the *accessory pancreatic duct* (fig. 1207). It runs upwards in front of the pancreatic duct, to which it is connected by a communicating duct, and opens into the duodenum about 2 cm. above and slightly ventral to the major duodenal papilla on a small rounded minor duodenal papilla. The terminal part of the accessory duct may fail to expand and the secretion from the lower part of the head of the pancreas is then diverted along the communicating duct into the main pancreatic duct.

Surface Anatomy.—The head of the pancreas lies within the curve formed by the first, second and third parts of the duodenum. The neck lies in the transpyloric plane, behind the pylorus. The body passes obliquely to the left and upwards for about 10 cm., its left part lying a little above the transpyloric plane. The tail lies a little above and to the left of the intersection of the transpyloric and left lateral planes.

Structure (fig. 1208).—In structure, the pancreas resembles the salivary glands. It differs from them, however, in certain particulars, and is looser and softer in its texture. It is not enclosed in a distinct capsule, but is surrounded by areolar tissue, which dips into its interior, and connects together the various lobules of which it is composed. Each lobule, like the lobules of the salivary glands, consists of one of the ultimate ramifications of the main duct, ending in a number of alveoli, which are

tubular and somewhat convoluted. The minute ducts (intercalary ducts) connected with the alveoli are narrow and lined with flattened cells. Where the ducts lead into the alveoli, their walls are lined with cubical cells which do not stain so deeply as the secreting cells of the alveoli; they are known as the *centro-acinar cells*. The true secreting cells, which line the wall of the alveolus, are columnar in shape and present two zones; an outer, clear and faintly striated, next the basement-membrane, and an inner, which contains secretory granules (trypsinogen). In hardened specimens the outer zone stains deeply with basic dyes, whereas the inner zone stains slightly. During activity the granular zone gradually diminishes in size; during the resting stages it gradually increases until it forms nearly three-fourths of the cell. Between the alveoli collections of cells are found which are arranged as syncytium-like aggregations and which are termed *interalveolar cell-islets*, or islands of Langerhans; they are rather more numerous in the tail of the pancreas than elsewhere. The cells of these stain lightly with hæmatoxylin or carmine, and are more or less polyhedral in shape, forming a network in which many capillaries ramify. There are two main types of cell in the islets, distinguished as A-cells and B-cells according to the special staining reactions of the granules they contain. When stained with Mallory-azan, the granules in the A-cells stain brilliant red, while those in the B-cells stain brown-orange. A few cells (the D-cells) are scattered in the islets whose granules stain blue; it is not

FIG. 1208.—Section of a portion of a pancreatic lobule. Stained with hæmatoxylin and eosin. $\times 300$. (Drawn from a preparation kindly lent to the Editors by Dr. E. E. Hewer.)



known whether these are a separate type of cell or are a stage in the development of the A or B cells. There is some evidence* of cyclical changes in the islets of the pancreas (of the rat) suggesting a transformation of *alveolar* cells into large B-cells; the latter becoming reduced in size and displaced towards the centre of the islets as they become senescent. The cell-islets produce insulin, the internal secretion of the pancreas which is necessary for carbohydrate metabolism. The B-cells undergo alteration in diabetes mellitus.

The wall of the pancreatic duct is thin, consisting of two coats, an external fibrous and an internal mucous; the latter is smooth, and lined with columnar epithelium among which goblet-cells are interspersed.

Vessels and Nerves.—The *arteries of the pancreas* are derived from the splenic artery, and from the pancreaticoduodenal branches of the hepatic and superior mesenteric arteries (pp. 798 and 799). Its *veins* open into the portal, splenic and superior mesenteric veins. Its *lymph vessels* are described on p. 899. Its *nerves*, derived from the vagus and splanchnic nerves, reach it through the splenic plexus. Secretory activity of the pancreas is largely under hormonal control.

* H. Hughes, *J. Anat.*, 81, 82-92, 1947.

Applied Anatomy.—Cysts of the pancreas may attain a large size, and cause symptoms by pressing on the stomach, Diaphragm or bile-duct. They generally push their way forwards between the stomach and transverse colon, and may then be felt in the upper part of the abdomen as a definite tumour in the median plane. The tumour is fixed and does not move with respiration. The pancreas is often the seat of cancer; this usually affects the head, and therefore speedily involves the bile-duct, leading to persistent jaundice; or it may press upon the portal vein, causing ascites, or involve the stomach, causing pyloric obstruction. The second part of the duodenum is occasionally encircled by the head of the pancreas (annular pancreas), and should the latter then be the seat of malignant disease or chronic inflammation it may cause obstruction of the duodenum. Similarly, if the common bile-duct lies in a canal in the head of the pancreas (p. 1451), chronic inflammatory disease of the pancreas may obstruct the duct and produce jaundice. Accessory nodules of pancreatic tissue may sometimes be present in the wall of the duodenum (most commonly), the jejunum, the ileum or the ileal diverticulum (p. 1427). Those in the duodenum may be associated with the occasional presence of duodenal diverticula. These take the form of small protrusions which involve all the coats of the duodenum, or only the mucous and submucous coats, and they are usually situated on the wall of the duodenum adjacent to the pancreas and in close relation to the opening of the bile duct.

THE LIVER (HEPAR) (figs. 1209 to 1211)

The **liver**, the largest gland in the body, is situated in the upper and right parts of the abdominal cavity, occupying almost the whole of the right hypochondrium, the greater part of the epigastrium, and not uncommonly extending into the left hypochondrium as far as the left lateral line. In the male it weighs from 1·4 to 1·6 kilogram., in the female from 1·2 to 1·4 kilogram. It is relatively much larger in the fœtus than in the adult, constituting, in the former, about one-eighteenth, and in the latter, about one-thirty-sixth of the entire body-weight. Its greatest transverse measurement is from 15 cm. to 20 cm. Vertically, near its right surface, it measures from 15 cm. to 17 cm., while its greatest anteroposterior diameter is on a level with the upper end of the right kidney, and is from 12 cm. to 15 cm.; opposite the vertebral column this diameter is reduced to about 7 cm. It is reddish-brown in colour and, although firm and pliant to the touch, it is friable and easily lacerated. For this reason wounds of the liver must not be too tightly sutured. Owing to its great vascularity, wounds of the liver cause considerable hæmorrhage. In spite of its relatively great weight, the liver, like the other abdominal organs, is maintained in its position, not by its peritoneal folds (p. 1458) or connective tissue attachments, but by the general intra-abdominal pressure due to the tonus of the abdominal muscles. Continuity of the hepatic veins with the inferior vena cava also constitutes a support.

When the liver has been hardened *in situ* it presents the appearance of a wedge, the base of which is directed to the right and the edge to the left. Symington described its shape as that 'of a right-angled triangular prism with the right angles rounded off'.

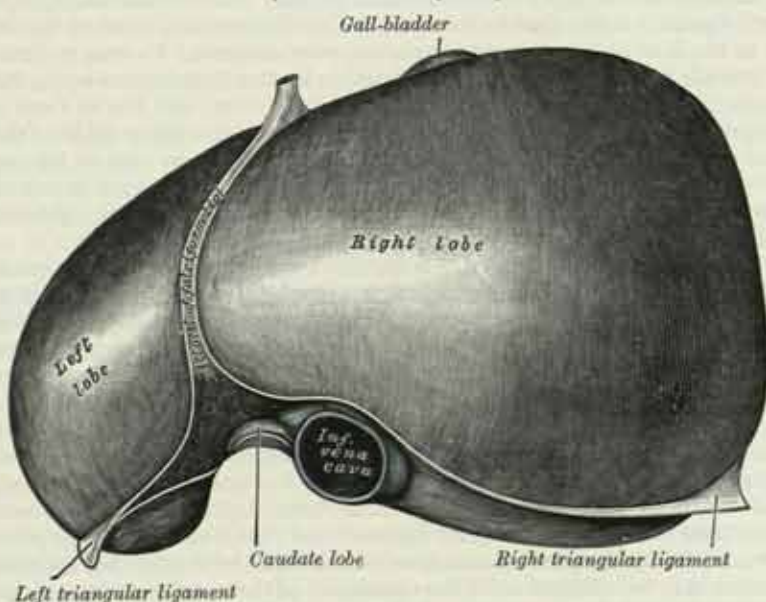
The liver possesses five surfaces, which will be described later, viz. superior, inferior, anterior, posterior, and right.

Borders.—The superior, anterior, and right surfaces are united by rounded borders, but a sharp margin, termed the *inferior border* (fig. 1198), separates the right lateral and anterior surfaces from the inferior or visceral surface. Somewhat rounded where it intervenes between the right lateral and inferior surfaces, it is thin and sharp where it forms the lower margin of the anterior surface and is marked by a notch, termed the *notch of the ligamentum teres*, in or just to the right of the median plane. Lateral to the fundus of the gall-bladder, which often corresponds to a second notch placed 4 to 5 cm. to the right of the median plane, this border generally corresponds with the costal margin. To the left of the fundus of the gall-bladder, it ascends less obliquely than the right costal margin and, crossing the infrasternal angle, passes behind the left costal margin in the neighbourhood of the tip of the eighth costal cartilage. Thereafter it ascends sharply and merges with the thin left margin of the left lobe. As it crosses the infrasternal angle the inferior border is closely related to the deep surface of the anterior abdominal wall and is readily accessible to examination in the living subject by percussion, though normally it is not palpable; in the median plane the inferior border of the liver lies on the transpyloric plane, about a hand's breadth below the xiphi-sternal joint (p. 1398). It

should be noted that in women and children this border usually lies at a slightly lower level, i.e. it tends to project downwards for a short distance below the right costal margin.

Lobes.—The liver is divided, very imperfectly, into a large right and a much smaller left lobe (*see also* p. 1462). On the anterior and superior surfaces the two lobes meet along the line of attachment of a sickle-shaped fold of peritoneum which passes to the liver from the anterior abdominal wall and the under surface of the Diaphragm and is termed the falciform ligament (p. 1458). On the posterior and inferior surfaces the separation is more obvious and is effected by two fissures which meet end to end at the left extremity of the porta hepatis; they are termed the fissure for the ligamentum venosum and the fissure for the ligamentum teres. The *fissure for the ligamentum venosum* is a deep cleft, lined with peritoneum, which descends on the posterior surface, nearer to its left than to its right limit. The *fissure for the ligamentum teres*, which is usually shallow, runs upwards and backwards on the inferior surface and extends from the inferior border of the liver to the left extremity of the porta hepatis.

FIG. 1209.—The superior, anterior, and right lateral surfaces of the liver.
(From a model by His.)



The *left lobe* is thin, flattened from above downwards and only about one-sixth of the size of the whole organ. It presents anterior, superior, posterior and inferior surfaces, which are described with the surfaces of the liver (p. 1459).

The *right lobe*, which is somewhat cuboidal in form, constitutes the remaining five-sixths of the organ. It contributes to all of the surfaces of the liver, with which its surfaces will be described (p. 1459). The portion of the right lobe which adjoins the left lobe on the inferior and posterior surfaces is further subdivided into two smaller lobes, termed the *quadrate* and *caudate* lobes.

The *quadrate lobe* is placed on the inferior surface, and is somewhat rectangular in outline. It is bounded in front by the inferior border of the liver: on the left by the fissure for the ligamentum teres: behind by the porta hepatis: and on the right by a shallow fossa which lodges the gall-bladder.

The *caudate lobe* is situated on the posterior surface. It is bounded on the left by the fissure for the ligamentum venosum: below by the porta hepatis: and on the right by the deep groove which lodges the upper portion of the inferior vena cava. Above, it is continuous with the superior surface to the right of the upper end of the fissure for the ligamentum venosum. Below and to the right the caudate lobe is connected to the rest of the right lobe by a narrow tongue of liver substance, termed the *caudate process*, which lies immediately behind the porta hepatis and forms the roof of the epiploic foramen. Below and to the left the caudate lobe

presents a small rounded projection, which is termed the *papillary process*. In addition, owing to the depth of the fissure for the ligamentum venosum, the caudate lobe possesses a peritoneal-covered anterior surface, which forms the posterior wall of the fissure and is in contact with the hepatic part of the lesser omentum.

The relations of the quadrate and caudate lobes will be described with the surfaces of the liver (pp. 1459 to 1461).

Peritoneal connexions of the liver.—With the exception of an extensive, triangular area on the posterior surface of the right lobe, the liver is almost completely invested with peritoneum. It is connected to the stomach and duodenum, to the Diaphragm and to the anterior abdominal wall by a number of peritoneal folds, and the lines along which they meet the organ are also necessarily devoid of a peritoneal covering. These folds include the falciform ligament, the right and left triangular ligaments, the coronary ligament and the lesser omentum.

The *falciform ligament* (fig. 1162) is a sickle-shaped fold, consisting of two closely applied layers of peritoneum, which connects the liver to the Diaphragm and the anterior abdominal wall. Its convex margin is fixed to the inferior surface of the Diaphragm and to the posterior surface of the anterior abdominal wall, extending downwards to the umbilicus; as this attachment ascends from the umbilicus it passes slightly to the right of the median plane. The concave margin of the falciform ligament is attached to the notch for the ligamentum teres on the inferior border of the liver and to its anterior and superior surfaces. Its base or free edge, which extends from the umbilicus to the notch for the ligamentum teres, contains the ligamentum teres and the small para-umbilical veins, and lies in front of the pyloric portion of the stomach. At its upper end the two layers of the falciform ligament separate from each other and expose a small triangular area on the superior surface of the liver which is devoid of peritoneum. The left layer becomes continuous with the anterior layer of the left triangular ligament: the right with the upper layer of the coronary ligament.

The *coronary ligament* (fig. 1210) is formed by the reflection of the peritoneum from the Diaphragm to the superior and posterior surfaces of the right lobe. It consists of an upper and a lower layer, continuous at their right extremities with the right triangular ligament of the liver but diverging widely to the left so as to enclose a large triangular area of the right lobe which is uncovered with peritoneum and is termed the 'bare area'. The upper layer is continuous with the right layer of the falciform ligament, skirts the upper end of the groove for the inferior vena cava anteriorly and then gradually descends from the posterior part of the upper surface to the upper part of the posterior surface. There it is continuous with the anterior layer of the right triangular ligament. The lower layer is continuous with the posterior layer of the right triangular ligament and passes almost horizontally along the lower limit of the posterior surface of the right lobe. In this situation the peritoneum may be reflected on to the upper part of the anterior surface of the right kidney (hepatorenal ligament) instead of on to the Diaphragm beyond the margin of that organ. At its left extremity the lower layer of the coronary ligament passes in front of the lower end of the groove for the inferior vena cava and becomes continuous with the line of peritoneal reflexion from the right border of the caudate lobe, i.e. the right margin of the upper recess of the omental bursa.

The *left triangular ligament* of the liver passes from the upper surface of the left lobe upwards and backwards to the under surface of the Diaphragm. It consists of two closely applied layers of peritoneum which become continuous with each other when traced to the left, where the ligament ends in a free margin. Traced to the right the anterior layer becomes continuous with the left layer of the falciform ligament, and the posterior layer with the anterior layer of the lesser omentum at the upper end of the fissure for the ligamentum venosum. It is placed in front of the abdominal part of the œsophagus, the upper end of the lesser omentum and part of the fundus of the stomach.

The *right triangular ligament* is a short V-shaped fold which connects the lateral part of the posterior aspect of the right lobe to the Diaphragm. The apex of the V forms a free right, or lower, margin for the ligament, around which its two layers become continuous with each other. The ligament really constitutes the right limit of the coronary ligament.

The *lesser omentum* has already been described (p. 1408) in detail. It will be sufficient to add that at the upper end of the fissure for the ligamentum venosum, its

anterior layer becomes continuous with the posterior layer of the left triangular ligament, and its posterior layer with the line of reflexion of the peritoneum from the upper end of the right border of the caudate lobe and so, indirectly, with the lower layer of the coronary ligament (fig. 1210).

Surfaces.—The *superior surface* of the liver (fig. 1209) includes portions of the right and left lobes. It fits under the vault of the Diaphragm, and is covered with peritoneum, except over a small triangular area where the two layers of the upper part of the falciform ligament diverge. Its right and left portions are convex, but its central part presents a shallow *cardiac impression*, which corresponds with the position of the heart on the upper surface of the Diaphragm. It is related to the diaphragmatic pleura of the right side and the base of the right lung, to the pericardium and ventricular part of the heart, and, to a much smaller extent, to the diaphragmatic pleura of the left side and the base of the left lung.

The *anterior surface*, which is triangular in shape, also comprises portions of both right and left lobes, and is covered with peritoneum except at the line of attachment of the falciform ligament. A large part of this surface is in contact with the Diaphragm, which separates it, on the right side, from the pleura and the sixth to the tenth ribs and their cartilages and, on the left side, from the seventh and eighth costal cartilages. The thin anterior margin of the base of the lung is related to the upper part of this surface, but the relationship is much more extensive on the right than it is on the left side. The median part of the anterior surface of the liver lies behind the xiphoid process of the sternum and the anterior abdominal wall in the infracostal angle.

The anterior surface may be marked out on the anterior aspect of the trunk as follows (fig. 1198): its upper border corresponds to a line drawn through, or a little below, the xiphisternal joint and ascending to the right to a point a little below the right nipple, and ascending less sharply to the left to a point a little below and medial to the left nipple; its right border corresponds to a curved line, convex to the right, drawn from the right end of the upper border to a point 1 cm. below the right costal margin at the tip of the tenth costal cartilage; its lower border is drawn by joining the ends of the upper and right borders, this line crossing the median plane at the level of the transpyloric plane and showing a slight concavity opposite the right linea semilunaris. The area on the anterior aspect of the trunk which is bounded on the right by the left part of the lower margin of the liver, above by the left lung, on the left by the spleen and below by the left costal margin, is called *Traube's space*; it overlies the stomach.

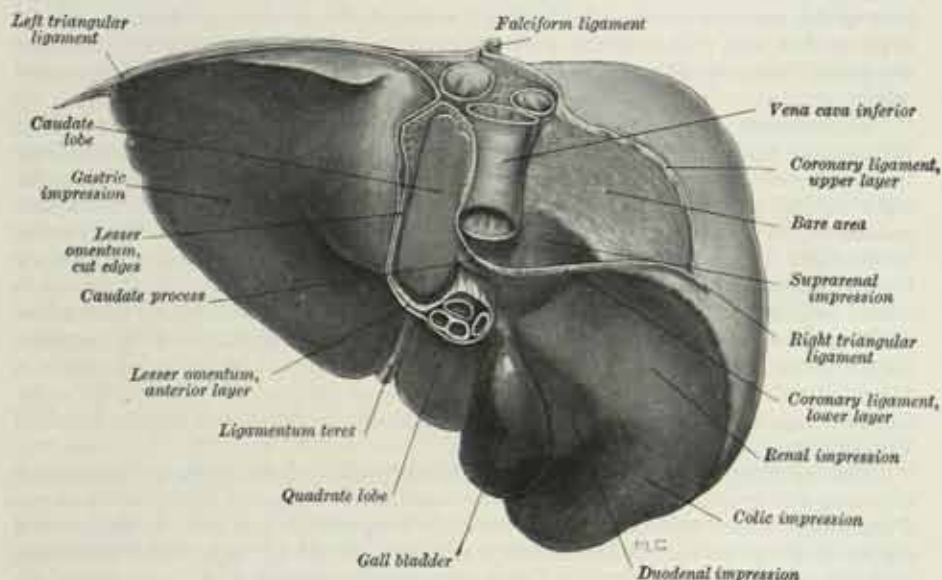
The *right surface* is convex from before backwards, and slightly so from above downwards. It is covered with peritoneum and is related to the right portion of the Diaphragm, which separates it from the right lung and pleura, and the right costal arches from the seventh to the eleventh inclusive. Over its upper third both lung and pleura intervene between the Diaphragm and the costal arches; over its middle third only the costodiaphragmatic recess of the pleura is interposed; over its lower third the Diaphragm is in actual contact with the costal arches.

The *posterior surface* includes portions of both right and left lobes; it is thick and convex on the right, but thin on the left. A deep concavity marks its median portion and corresponds with the forward convexity formed by the vertebral column (fig. 1209). A large part of this surface of the right lobe is devoid of peritoneal covering and is attached to the Diaphragm by areolar tissue. This non-peritoneal surface constitutes the 'bare area' of the liver. It is triangular in outline and is limited above and below by the superior and inferior layers of the coronary ligament. Its base is formed by the deep groove for the inferior vena cava, while its apex, directed downwards and laterally, corresponds with the right triangular ligament. The *groove for the inferior vena cava* is a deep depression, occasionally a complete tunnel, on the posterior surface of the liver and is devoid of peritoneal covering. It lodges the upper part of the vessel and its floor is pierced by the hepatic veins (p. 871). At its lower end the groove is separated from the porta hepatis in front by the caudate process. Immediately lateral to the lower end of the groove the 'bare area' presents a somewhat triangular impression on the formalin-hardened liver, which lodges the upper part of the right suprarenal gland and is therefore termed the *suprarenal impression*. On the left side of the groove for the inferior vena cava the *caudate lobe* occupies the rest of the posterior surface of the right lobe. It lies in the upper recess of the omental bursa, and is usually described

as forming its anterior wall. This description is not quite accurate, because the peritoneum covering its posterior aspect is continued round its left border on to its anterior aspect, which forms the posterior wall of the fissure for the ligamentum venosum (fig. 1210). The caudate lobe should therefore be regarded as projecting into the upper recess of the omental bursa from its right border. The posterior surface of the caudate lobe is related to the crura of the Diaphragm above the aortic opening and to the right phrenic artery, and is separated by them from the descending thoracic aorta. The *papillary process* often projects downwards in front of the origin of the cœliac artery.

The lips of the *fissure for the ligamentum venosum* separate the posterior aspect of the caudate from the posterior aspect of the left lobe. The fissure itself cuts deeply into the liver in front of the caudate lobe and contains the two layers of the lesser omentum. At its lower end it curves laterally below, or in front of, the papillary process, and reaches the left extremity of the porta hepatis. The *ligamentum venosum*, which is the fibrous remnant of the ductus venosus (p. 175), is attached below to the upper border of the left branch of the portal vein. It ascends in the

FIG. 1210.—The liver viewed from behind, showing the peritoneal connexions divided close to the viscus.



floor of the fissure and passes laterally at the upper end of the caudate lobe to join the left hepatic vein near its point of entry into the inferior vena cava, or sometimes the vena cava itself.

The posterior aspect of the left lobe is marked by a shallow notch near the upper end of the fissure for the ligamentum venosum. It is occupied by the abdominal portion of the œsophagus and is termed the *œsophageal impression*. To the left of this impression the left lobe is related to a part of the fundus of the stomach.

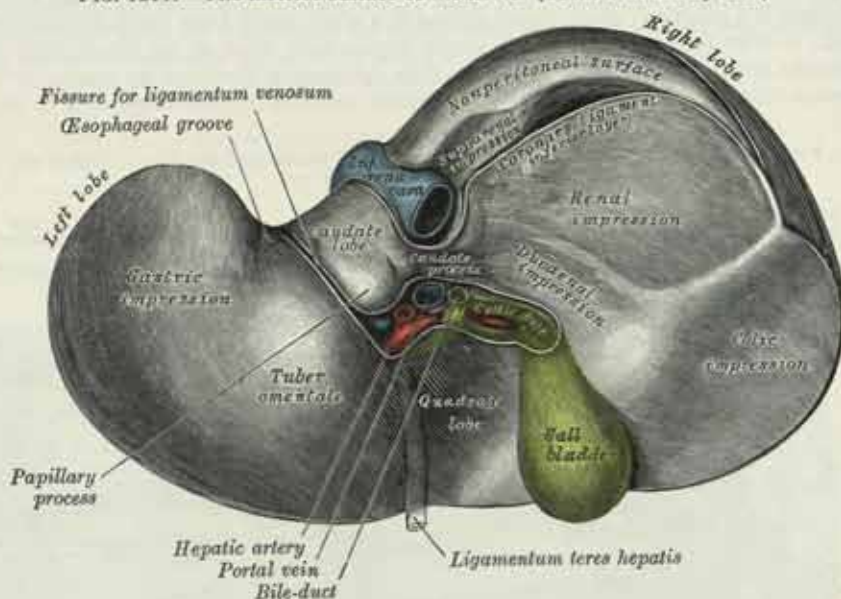
The *inferior* or *visceral surface* is directed downwards, backwards and to the left, and, in the formalin-hardened organ, bears the imprints of the neighbouring viscera. It is invested with peritoneum except at the porta hepatis, the fissure for the ligamentum teres and the fossa for the gall-bladder. On the inferior surface of the left lobe, in direct continuity with the œsophageal impression, the *gastric impression* is moulded over the stomach. On the right of this impression there is a rounded ridge, the lower part of which is sometimes prominent and is termed the *omental tuberosity*. This ridge occupies the concavity of the lesser curvature of the stomach and is in contact with the lesser omentum. The *fissure for the ligamentum teres* is a cleft of variable depth which passes upwards and backwards from the corresponding notch on the inferior border of the liver to the left end of the porta hepatis where it meets the lower end of the fissure for the ligamentum venosum. It forms the left boundary of the quadrate lobe and may be, partially or completely, bridged over by

a band of liver substance. Its floor lodges the *ligamentum teres of the liver*, which is the obliterated remains of the left umbilical vein in the foetus (p. 725). Commencing at the umbilicus it ascends in the free margin of the falciform ligament to the inferior border of the liver, traverses the fissure and ends by joining the left branch of the portal vein at the left extremity of the porta hepatis opposite the attachment of the *ligamentum venosum*.

The gastric impression may be continued on to the anterior part of the *quadrate lobe*, which is hollowed out and moulded over the pyloric part of the stomach and the beginning of the duodenum, when these organs are dilated. The posterior, or upper, part of the quadrate lobe is in contact with the right free border of the lesser omentum and its contained structures. When the stomach is empty the quadrate lobe is related to the first part of the duodenum and a portion of the transverse colon.

The *porta hepatis* is placed on the inferior surface of the liver between the quadrate lobe in front and the caudate process behind. It is a deep fissure which runs transversely between the upper ends of the fissure for the *ligamentum teres* and the

FIG. 1211.—The inferior surface of the liver. (From a model by His.)



fossa for the gall-bladder. Through the porta hepatis the portal vein, the hepatic artery and the hepatic plexus of nerves enter the liver, and the right and left hepatic and the cystic ducts and some lymph vessels emerge. The hepatic ducts are situated anteriorly, the portal vein and its right and left branches posteriorly and the hepatic artery and its right and left branches are intermediate in position.

The *caudate process* connects the lower and lateral part of the caudate lobe to the remainder of the right lobe. It is placed behind the porta hepatis and in front of the inferior vena cava, and is covered with peritoneum. It forms the roof of the epiploic foramen.

The *fossa for the gall-bladder* forms the right boundary of the quadrate lobe and extends from the inferior border of the liver to the right extremity of the porta hepatis. It is usually shallow and devoid of peritoneal covering, but the breadth of this bare area is subject to individual variation.

To the right of the fossa for the gall-bladder, the inferior surface of the right lobe is marked by three impressions, viz. colic, renal and duodenal. The *colic impression* is related to the right colic flexure and is placed on the anterior part of the area, immediately adjoining the inferior border of the liver. The *renal impression* is usually well marked; it is situated behind the colic impression and is separated from the neck and the adjoining part of the gall-bladder by the duodenal impression. It is related to the upper part of the anterior surface of the right kidney, and in its supromedial part to the lower pole of the right suprarenal gland. When the lower

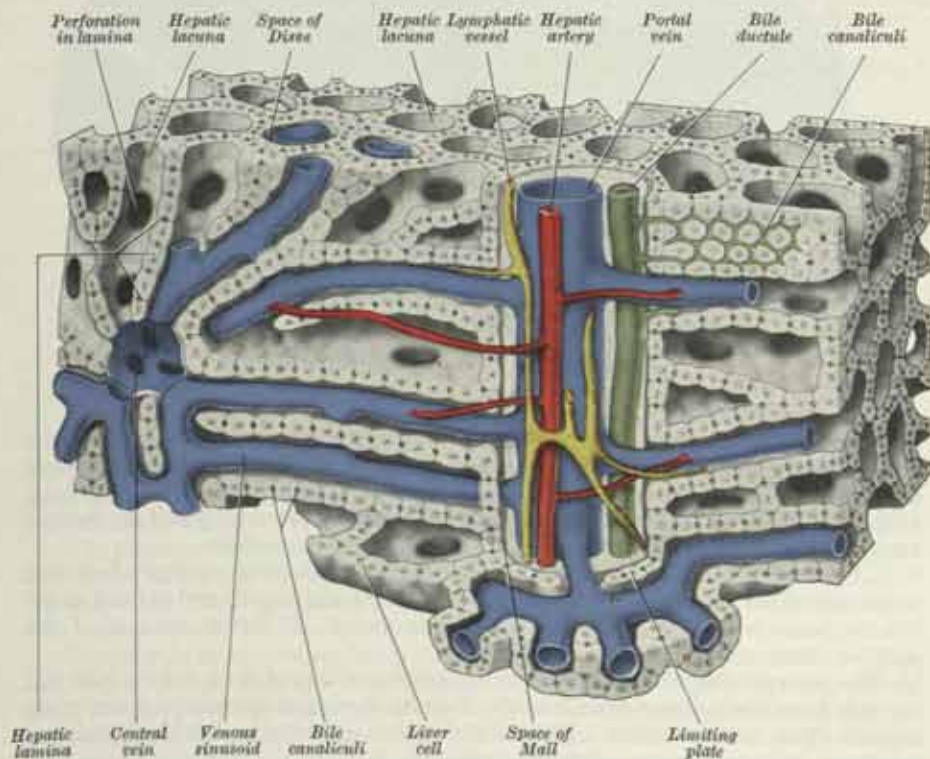
layer of the coronary ligament is reflected from the liver on to the right kidney, the renal impression extends for a short distance on to the lower part of the 'bare area'. The *duodenal impression* lies to the lateral side of the neck and adjoining part of the gall-bladder, and is related to the termination of the first part and the commencement of the second part of the duodenum.

The relations of the liver show considerable variation, for which posture and the movements of respiration are only partly responsible. *Those which have been enumerated refer to the body in the supine recumbent position.*

The two lobes of the liver described above represent the conventional division of the liver into right and left 'anatomical' lobes. However, the liver can also be divided into two 'physiological' lobes by an oblique plane which passes upwards and slightly to the left from the middle of the caudate lobe and the fossa for the gall-bladder on the visceral surface. These two lobes are supplied respectively by the right and left branches of the portal vein and the hepatic artery and their bile drains into the right and left hepatic ducts.

The branches of the portal vein and the tributaries of the hepatic veins are more numerous before birth; after birth a reduction in their number takes place by fusion of vessels or by degeneration. After the fourth month of foetal life the ductus venosus is a relatively small vessel arising at a sharp angle from the (left) umbilical vein, so that in later foetal life it would appear that most of the blood from the placenta must pass through the liver, little by-passing the liver by means of the ductus venosus. In a few fetuses the ductus venosus remains large, and in these

FIG. 1212.—A diagrammatic illustration of the structure of the liver. Based on H. Elias (*Biol. Rev.*, 1955, vol. 30).



cases the right (physiological) lobe of the liver may degenerate. In the foetus the portal vein joins the umbilical vein in a smooth curve to the right; this direction is maintained after birth and there is a sharp angle between the trunk of the portal vein and its left branch, so that the left (physiological) lobe of the liver would appear to be at a circulatory disadvantage and not able to keep pace with the growth of the right lobe. At the left end of the left lobe in the adult there is sometimes a fibrous band (*the fibrous appendix of the liver*), which represents the atrophied

remains of the more extensive left lobe in the young child; it contains atrophied remnants of bile-ducts, known as the vasa aberrantia of the liver. Similar remnants may be present in the edges of the left lobe and near the inferior vena cava. Occasionally the lower border of the right lobe, a little to the right of the gall-bladder, may project downwards for a considerable distance as a broad tongue-like process (Riedel's lobe).

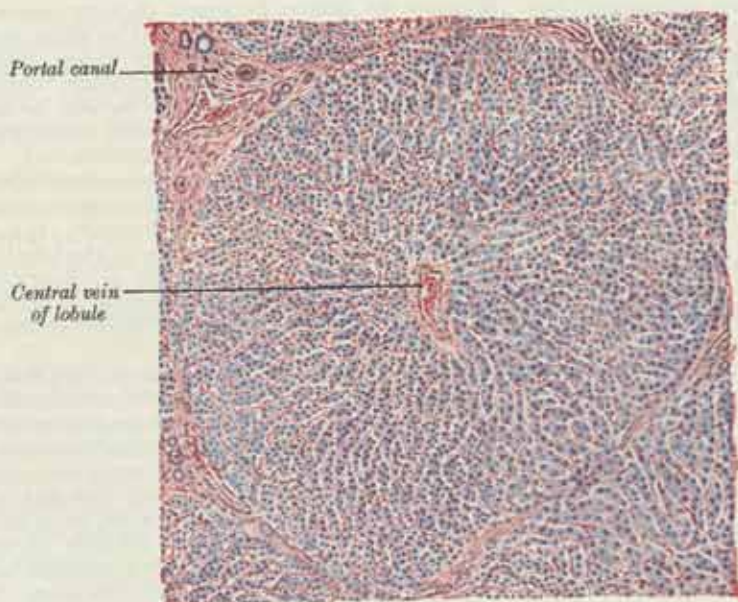
Vessels and Nerves.—The vessels connected with the liver are the portal vein, and the hepatic artery and veins.

The *portal vein* and *hepatic artery*, accompanied by numerous nerves, ascend between the layers of the lesser omentum to the porta hepatis, where each divides into two branches; the *bile-duct* and lymph vessels descend from the porta hepatis between the layers of the same omentum. They are all enveloped in a loose areolar tissue, termed the *perivascular fibrous capsule* (or hepato-biliary capsule of Glisson), which accompanies the vessels in their course through the portal canals in the interior of the liver and is continuous with the fibrous capsule of the liver.

The *hepatic veins* (fig. 1212) convey the blood from the liver to the inferior vena cava, and are described on p. 873. They have very little fibrous investment, but what there is binds them closely to the walls of the canals through which they run; so that, on section of the liver, they remain widely open and are solitary, and may be easily distinguished from the branches of the portal vein, which are more or less collapsed, and always accompanied by an artery and duct.

The *lymph vessels* of the liver are described on p. 900.

FIG. 1213.—A section through a hepatic lobule. Human. Stained with hæmatoxylin and eosin. $\times 670$. (After Sobotta.)



The *nerves* of the liver are derived from the hepatic plexus (p. 1217) and contain both sympathetic and parasympathetic (vagal) fibres. They enter the liver at the porta hepatis and for the main part accompany the blood vessels and bile ducts; very few run amongst the liver cells and the mode of termination of these is not certainly known.

Structure of the liver (fig. 1212).—The greater part of the liver is invested with peritoneum, which covers a thin capsule of connective tissue. The liver consists of a very large number of polyhedral *hepatic lobules* (which often appear to be hexagonal in histological sections), each being about 1 mm. in diameter and having a small *central vein* (a tributary of the hepatic veins) as its central axis and surrounded at its edges by *portal canals* (fig. 1213). Each portal canal contains a branch of the portal

* For a detailed review of the structure of the liver, consult Hans Elias, *Liver Morphology*, in *Biological Reviews*, 1955, 30, 263-310.

vein, a branch of the hepatic artery and an interlobular bile ductule, all these structures ('the portal triad') being surrounded by a connective tissue sheath, the *perivascular fibrous capsule*. In the adult pig, each hepatic lobule is sharply marked off from neighbouring lobules by connective tissue septa, but in this respect the pig's liver is atypical, the fibrous septa being pathological and produced by a portal cirrhosis. In man (and most mammals) the hepatic lobules are not separated by such septa. A 'portal lobule', on the other hand, consists of the adjoining parts of three hepatic lobules, the bile from which drains into a bile ductule in the portal canal at the meeting place of the three hepatic lobules; in histological sections a 'portal lobule', triangular in shape, may be visualised by lines joining the central veins of three adjacent hepatic lobules. Neither the hepatic nor the portal lobules are to be considered as fixed anatomical entities; under normal conditions the 'hepatic lobular structure' is evident, but this can be changed to a 'portal lobular structure' by alteration in the relative blood-pressure in the portal and hepatic veins (e.g. by raising the hepatic venous pressure or lowering the portal pressure), the change being reversible. Such alterations in the venous pressure gradients are produced by various pathological conditions.

A liver cell is polyhedral in shape, having 5 to 12 sides, and is from 12μ to 25μ in diameter. It has one or two spherical nuclei and its cytoplasm contains fine basophil granules and variable amounts of glycogen granules and fat droplets.

It has been customary to consider the hepatic lobule as consisting of 'cords' of liver cells radiating from a central vein, each 'cord' consisting of two rows of liver cells with a bile capillary between them, and radiating venous sinusoids lying between adjacent 'cords' in such a way that the bile capillary is separated from the sinusoids by the thickness of a liver cell. Recent studies, however, indicate that the liver cells are really arranged as plates or sheets (*hepatic laminae*), one cell thick, which form a continuous system throughout the liver (fig. 1212). These laminae form a 'wall-work' or 'muralium' and are irregularly arranged, with interlaminal bridges of liver cells connecting adjacent laminae. Between the laminae lie spaces (*hepatic lacunae*) which contain the venous sinusoids, and the laminae are perforated to allow the passage of anastomoses between the sinusoids. Where the liver cells adjoin portal canals or hepatic vein tributaries, they form a sheet, called a *limiting plate*, which surrounds the vessels and is perforated by radicles of these vessels as well as by branches of the hepatic artery and bile ductules; a similar limiting plate, consisting of a single layer of liver cells, lies beneath the capsule of the liver.

In histological sections of the liver (fig. 1213), the rows of liver cells seen radiating from the central vein to the periphery of the hepatic lobule really represent sections through the hepatic laminae. These rows of cells, with intervening sinusoids, do not pass regularly and straight like the spokes of a wheel to the periphery of the lobule, but pursue irregular courses, because the hepatic laminae themselves are irregular and branched. Some of the rows of cells (and sinusoids) pass at the periphery of the lobule between adjacent portal canals, while others pursue very indirect courses between the central vein and the portal canals.

The intralobular venous sinusoids are wider than blood capillaries and are lined by endothelial cells which are all potentially phagocytic and known as the stellate cells of Kupffer. The radicles of the portal vein contained in the portal canals give off branches, called *inlet venules*, which pass through holes in the limiting plate surrounding the portal canal in order to enter the hepatic lobules, where they become continuous with the sinusoids. The sinusoids convey blood from the interlobular branches of the portal vein (in the portal canals) to the central veins. The sinusoids lie in the hepatic lacunae between the hepatic laminae, and are separated from the liver plates by a potential space (the space of Disse), which becomes distended in conditions of anoxia, when plasma permeates through the walls of the sinusoids. The space of Disse is continuous at the periphery of the lobule with a space (the space of Mall) around the vessels and bile ductules in the portal canals, and it is in the latter space that the lymph vessels of the liver commence (as in other organs) by blind ends. Very few, extremely small lymph vessels penetrate into the periphery of the lobule.

The central veins from adjacent lobules join to form *sublobular veins* and these in their turn unite to form the *hepatic veins*, which drain the blood from the liver into the inferior vena cava.

In the hepatic lobules, minute bile capillaries, the *bile canaliculi*, form networks of polygonal meshes, each mesh surrounding an individual liver cell except on the surfaces of the cell apposed to the venous sinusoids. In the fresh organ the bile canaliculi do not give off diverticula nor do they enter the liver cells. Individual bile canaliculi therefore lie between the walls of adjoining liver cells and, in fact, studies with the electron microscope have revealed that the walls of the canaliculi are formed by a condensation of the superficial parts of the cytoplasm of the liver cells themselves. This relationship between the bile canaliculi, the liver cells and the venous sinusoids is reflected in the transformation of blood bilirubin into bile bilirubin. Blood bili-

rubin, which is formed by the cells of the reticulo-endothelial system by the disintegration of hæmoglobin, passes from the sinusoids into the liver cells and is thence excreted into the bile canaliculi. In its passage through the liver cell it undergoes a change which results in bile bilirubin and blood bilirubin giving different reactions to the van den Bergh tests. At the periphery of the hepatic lobules the bile canaliculi join to form very thin intralobular bile ductules, which in turn enter the interlobular bile ductules in the portal canals. The bile ductules in the portal canals are lined by columnar cells which may contain crystals of cholesterol and droplets of fat.

The terminal branches of the hepatic arteries, contained in the portal canals, give off branches which enter the inlet venules, while others penetrate into the lobules to join the venous sinusoids. The sinusoids therefore contain mixed venous and arterial blood which nourishes the liver cells. The composition, and velocity of the blood streaming at any time through any minute area of the liver may change and be adapted to the necessities of the moment by sphincteric arrangements in the inlet venules and in the branches of the hepatic arteries, and by the contractile walls of the sinusoids. The interlobular branches of the hepatic arteries also give off radicles to supply the structures in the portal canals. Each 'portal triad' (branches of the hepatic arteries, portal vein and bile ducts) supplies its own sharply delimited territory, and normally there are no anastomoses between these territories. On the other hand, the hepatic veins for the main part run independently of the portal veins, hepatic arteries and bile ductules and cross the boundary lines of the territories of the liver supplied by the latter structures.

During fetal life the liver acts as one of the main hæmatopoietic organs, both red and white blood corpuscles being developed in the mesenchyme covering the endothelium of the sinusoids (p. 51).

THE EXCRETORY APPARATUS OF THE LIVER

The excretory apparatus of the liver consists of (1) the *common hepatic duct*, formed by the junction of the right and left hepatic ducts, which leave the liver at the porta hepatis; (2) the *gall-bladder*, which serves as a reservoir for the bile; (3) the *cystic duct*, or duct of the gall-bladder; and (4) the *bile-duct*, formed by the junction of the common hepatic and cystic ducts.

The common hepatic duct.—Two main ducts (right and left hepatic) issue from the liver and unite near the right end of the porta hepatis to form the common hepatic duct, which passes downwards for about 3 cm., and is joined on its right side and at an acute angle by the cystic duct; by the union of the common hepatic with the cystic duct the bile-duct is formed (fig. 1215). The common hepatic duct is on the right of the hepatic artery and in front of the portal vein.

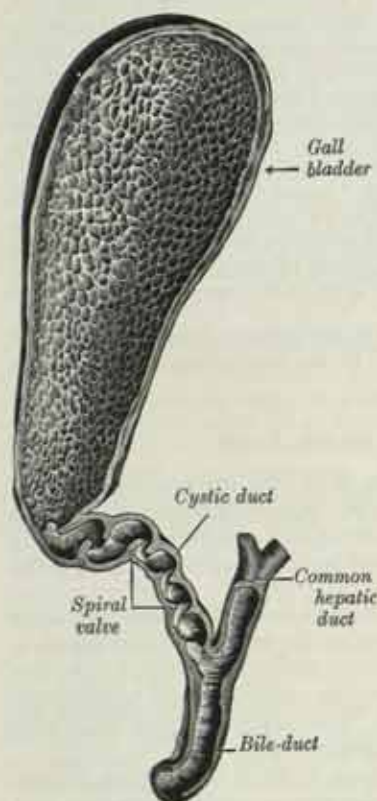
The gall-bladder [*vesica fellea*] (figs. 1211, 1214, 1215) is a slate-blue, conical or pear-shaped sac lodged in a fossa on the under surface of the right lobe and extending from near the right extremity of the porta hepatis to the inferior border of the liver. Its upper surface is attached to the liver by connective tissue; its under surface and sides are covered with peritoneum continued from the surface of the liver. Occasionally it is completely invested with peritoneum and may be connected to the liver by a short mesentery. It is from 7 cm. to 10 cm. long, 3 cm. broad at its widest part, and holds from 30 c.cm. to 50 c.cm. It is divided into a fundus, body and neck.

The *fundus*, or expanded end, is directed downwards, forwards and to the right. It projects beyond the inferior border of the liver, and comes into relationship with the posterior surface of the anterior abdominal wall below the ninth right costal cartilage, and behind the point where the lateral edge of the right Rectus abdominis crosses the costal margin; posteriorly the fundus is in relation with the transverse colon, near its commencement. It is entirely covered with peritoneum. The *body* is directed upwards, backwards and to the left; near the right end of the porta hepatis it is continuous with the neck. It is in relation by its upper surface, with the liver; by its under surface with the right part of the transverse colon; and farther back with the first part of the duodenum and the upper end of the second part. The *neck* is narrow; it curves upwards and forwards, and then, turning abruptly backwards and downwards, becomes continuous with the cystic duct; at its point of continuity with the cystic duct there is a constriction. The neck is attached to the liver by areolar tissue in which the cystic artery is imbedded. The mucous membrane which lines the neck projects into its lumen in the form of oblique ridges, forming a sort of spiral valve; when the neck is distended, this valve causes the surface of the neck to present a spiral constriction.

From the right wall of the neck of the gall-bladder a small pouch may project

downwards and backwards towards the duodenum. This pouch, often termed Hartmann's pouch, although originally described by Broca, has been regarded as a constant feature of the normal gall-bladder, but investigations* have shown that it is always associated with pathological conditions, especially dilatation. When the pouch is well marked the cystic duct arises from its *upper and left wall* and not from what appears to be the

FIG. 1214.—The gall-bladder and bile-ducts laid open. (Spalteholz.)



apex of the gall-bladder. The **cystic duct** (figs. 1214, 1215), from 3 cm. to 4 cm. long, passes backwards, downwards and to the left from the neck of the gall-bladder, and joins the common hepatic duct to form the bile-duct; it runs parallel with and adheres to the common hepatic duct for a short distance before joining with it. The junction is usually situated immediately below the porta hepatis, but it may be at a considerably lower level. In the latter event the cystic duct lies in the right free margin of the lesser omentum. The mucous membrane lining its interior is thrown into a series of crescentic folds, from five to twelve in number, similar to those found in the neck of the gall-bladder. They project into the duct in regular succession, and are directed obliquely round the tube, presenting much the appearance of a crescentic, *spiral valve* (fig. 1214). When the duct is distended, the spaces between the folds are dilated, and the exterior of the duct appears twisted in the same manner as the neck of the gall-bladder.

The **bile-duct** [ductus choledochus] is formed near the porta hepatis by the junction of the cystic and common hepatic ducts; it is about 7 cm. long, and of the diameter of a goose-quill.

It runs at first downwards, backwards and slightly to the left, anterior to the epiploic foramen; here it lies in the right border of the lesser omentum, in front of the right edge of the portal vein, and on the right of the hepatic artery (fig. 1215). It passes behind the first part of the duodenum with the gastroduodenal artery on its left, and then runs in a groove on the upper and lateral part of the posterior surface of the head of the pancreas (fig. 1206); here it is situated in front of the inferior vena cava, and is sometimes completely imbedded in the pancreatic substance (pp. 1451, 1456). At the left side of the second part of the duodenum it comes into contact with the pancreatic duct and accompanies it into the wall of this part of the gut, and there the two ducts unite to form the *hepatopancreatic ampulla* (p. 1454); the distal, constricted end of this ampulla opens into the second part of the duodenum on the summit of the major duodenal papilla (fig. 1207) from 8 to 10 cm. from the pylorus (p. 1425). J. Kirk† failed to find an ampulla in seven adults and one full-time foetus which he examined, although a well-marked ampulla was present in another full-time foetus.

The bile-duct may be indicated on the anterior surface of the abdomen by a line which begins 5 cm. above the transpyloric plane and 2 cm. to the right of the median plane, and runs downwards for 7.5 cm.

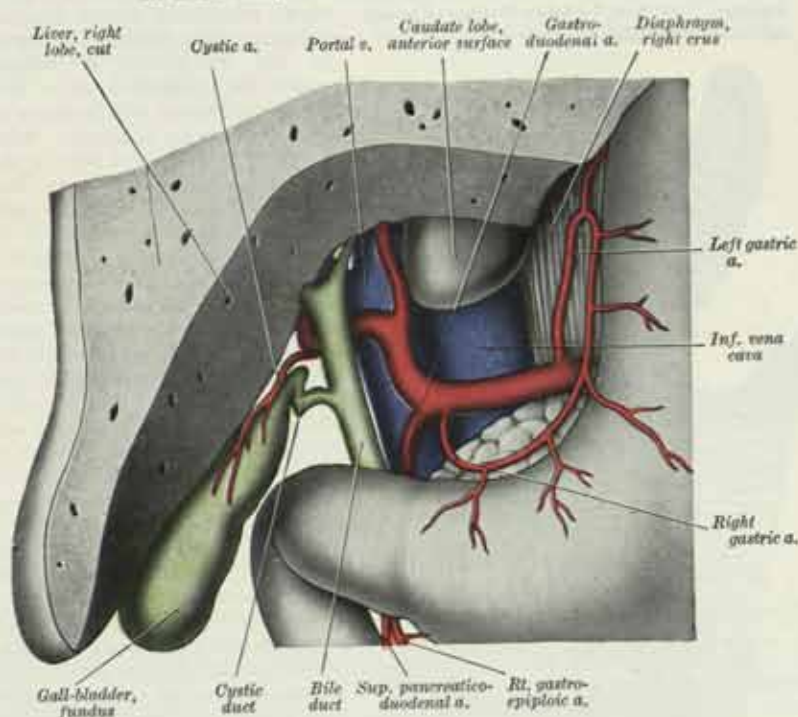
Vessels and nerves.—The cystic artery (p. 799), usually a branch of the right division of the hepatic artery, divides into two branches, a lower one, which passes to the under surface of the gall-bladder, and an upper one, which runs in the areolar tissue between the upper surface of the gall-bladder and the visceral surface of the liver, to both of which it gives branches. The cystic vein, formed by the union of

* F. Davies and H. E. Harding, *Lancet*, i, 193, 1942.

† *J. Anat.*, 78, 1944.

tributaries which accompany the branches of the cystic artery, ends in the right branch of the portal vein. In the areolar tissue between the gall-bladder and the liver, small veins connect the veins of the gall-bladder with those in the substance of the liver. The main blood supply of the bile duct is from the retroduodenal artery, which usually arises from the gastroduodenal artery and passes to the right behind the first part of the duodenum and in front of the bile duct, giving off an ascending branch to supply the upper part of the duct. The main artery passes down on the right side of the duct, supplying branches to it, and ends by anastomosing with the posterior division of the inferior pancreaticoduodenal artery in the vicinity of the hepatopancreatic ampulla. In cases where this anastomosis is poor, ligation of the retroduodenal artery may result in gangrene or stricture of the bile duct.* The lymph vessels of the gall-bladder are described on p. 901. The nerves of the gall-bladder, which are mainly sympathetic, are derived from the celiac plexus and pass along the hepatic artery and its branches. Fibres from the right phrenic nerve, through the communications

FIG. 1215.—Drawing of a dissection to show the relations of the hepatic artery, bile-duct and portal vein in the lesser omentum.



between the phrenic plexus and the celiac plexus, also appear to reach the gall-bladder in the hepatic plexus, as evidenced by the referred 'shoulder pain' experienced in diseases of the gall-bladder.

Variations in the bile-ducts are common. The cystic and common hepatic ducts may remain separate until they pass behind the first part of the duodenum; the cystic duct may pass behind the common hepatic duct and join the latter on its posterior or left surface; the bile-duct and the pancreatic duct may open separately into the duodenum or they may join together before passing through the duodenal wall; the cystic artery may arise from the hepatic artery and pass behind the bile-duct or the common hepatic duct.

Structure (fig. 1216).—The gall-bladder has three coats: serous, fibromuscular and mucous.

The *external* or *serous coat* is derived from the peritoneum; it completely invests the fundus, but covers only the under surfaces and sides of the body and neck.

The *fibromuscular coat*, a thin but strong layer, consists of dense, fibrous tissue, mixed with plain muscular fibres, which are disposed chiefly in a longitudinal direction, a few running transversely.

The *internal* or *mucous coat* is loosely connected with the fibrous layer. It is generally of a yellowish-brown colour, and is elevated into minute rugæ which give it a honeycomb appearance (fig. 1214). It is deeply stained with bile after death. The

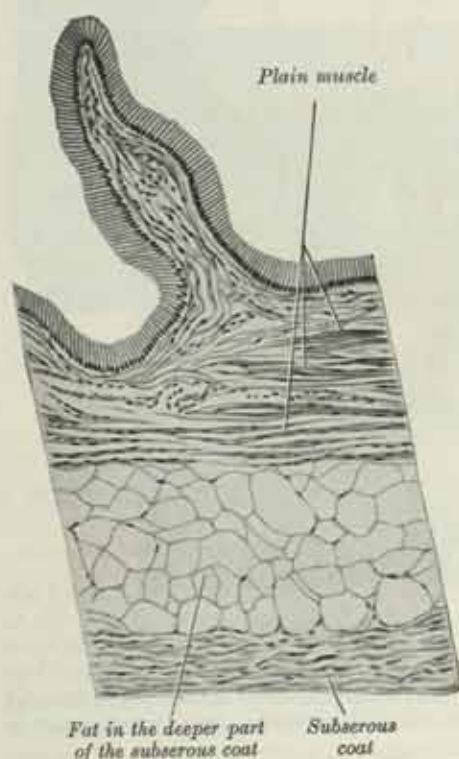
* F. A. Henley, *Brit. J. Surgery*, 1955, 43, 75.

mucous coat of the gall-bladder is continuous through the common hepatic duct with that of the ducts of the liver, and through the bile-duct with that of the duodenum. Its epithelium is columnar, and actively absorbs fluid (saline) from the bile, rendering it more concentrated. It also secretes mucus (fig. 1217).

The coats of the large biliary ducts are an external or fibrous, and an internal or mucous. The fibrous coat is composed of strong fibro-areolar tissue, with a certain amount of muscular tissue, arranged, for the most part, in a circular manner around the ducts. The mucous coat is continuous with the lining membrane of the hepatic ducts and gall-bladder, and also with that of the duodenum; and, like the mucous membrane of these structures, its epithelium is of the columnar variety. It is provided with numerous mucous glands, which are lobulated and open by minute orifices scattered irregularly in the larger ducts.

The circular muscle around the lower part of the bile-duct, including the ampulla and the terminal part of the main pancreatic duct, is called the *sphincter of the hepato-pancreatic ampulla* (or the sphincter of Oddi). The mechanism for the emptying of the gall-bladder appears to be under hormonal, rather than nervous control. The presence of fat or acid in the duodenum is believed to cause the liberation of a hormone (cholecystokinin) which stimulates the gall-bladder to contract. When the pressure of the stored bile in the gall-bladder exceeds 100 mm. bile, the gall-bladder contracts, the sphincter of Oddi relaxes and bile is poured into the duodenum. Kirk * maintains that there is no sphincteric arrangement of the musculature around the opening of the bile and pancreatic ducts into the duodenum, but that the *sphincter of Oddi* surrounds the bile-duct as it passes through the sub-mucosal zone of the duodenal wall and is continuous with the circular muscle coat of the duodenum which is thickened at this site. The terminal part of the united bile and pancreatic ducts is packed with villous, valvular folds of the mucous membrane and the muscle fibres extend into the connective tissue cores of these folds. This arrangement suggests that contraction of the muscle fibres results in retraction and erection or aggregation of the folds, thus preventing reflux of duodenal contents into the ducts and controlling the exit of bile into the duodenum. In the cat, stimulation of branches of the vagus nerves to this region results in relaxation of the opening of the bile-duct into the

FIG. 1216.—A section through a part of the peritoneal-covered portion of the wall of the gall-bladder. $\times 6200$. (After Rauber-Kopsch; semi-diagrammatic.)



duodenum; in the human, the myenteric (*Auerbach's*) plexus is well developed at the site of termination of the ducts. Inflammatory swelling of the villous folds may obstruct the ducts.

Applied Anatomy.—On account of its large size, its fixed position, and its friability, the liver is more frequently ruptured than any of the other abdominal viscera. The rupture may vary from a slight scratch to an extensive and complete laceration of its substance, dividing it into two parts. Sometimes an internal rupture, without laceration of the peritoneal covering, takes place, and such injuries are more easily repaired; but small tears of the surface may also heal; when, however, the laceration is extensive, death usually takes place from hæmorrhage, on account of the fact that the hepatic veins are contained in rigid canals in the liver-substance and are unable to contract, and moreover are unprovided with valves. The liver may also be torn by the end of a broken rib perforating the Diaphragm.

Abscess of the liver may enlarge in many different directions. Thus it has been known to burst into the lungs, when the pus is coughed up; or into the stomach,

* J. Kirk, *J. Anat.*, 78, 1944. See also G. Gordon-Taylor, *Brit. Med. J.*, 2, 1942.

when the pus is vomited; it may burst into the colon, or duodenum; or, by perforating the Diaphragm, it may empty itself into the pleural cavity. It often makes its way forwards, and points on the anterior abdominal wall; it may burst into the peritoneal or pericardial cavities.

Hydatid cysts are more often found in the liver than in any of the other viscera. The reason for this is not far to seek. The embryo of the egg of the *Tænia echinococcus*, being liberated in the stomach by the disintegration of its shell, bores its way through the gastric walls and usually enters a blood-vessel, and is carried by the bloodstream to the hepatic capillaries, where its onward course is arrested, and where it undergoes development into the fully formed hydatid.

There is some evidence that the blood-streams conveyed to the portal vein by the superior mesenteric vein and the splenic vein remain largely separate from each other and pass respectively along the right and left branches of the portal vein to the right and left physiological lobes (p. 1462) of the liver, e.g. embolic abscesses may be more pronounced in the right lobe than the left, if the primary infection lies in a part of the gut drained by the superior mesenteric vein, and in the left lobe if the primary site

FIG. 1217.—A transverse section through the columnar epithelium lining the gall-bladder. Highly magnified.

Note the granules of mucin which lie between the nuclei of the epithelial cells and their free borders.



is in splenic vein territory. Some injection experiments in living animals also indicate the tendency for the two venous streams to remain separate in the portal vein. On the other hand, if radio-opaque material is injected into the spleen in man, it is conveyed along the splenic vein and most of it passes into the right 'physiological' lobe, indicating that there may be a crossing of the blood-streams from the splenic and superior mesenteric veins in the portal vein.

The gall-bladder may become distended in cases of obstruction of the cystic duct or of the bile-duct, or from a collection of gall-stones in its interior, thus forming a large tumour. The swelling is pear-shaped, and projects downwards and forwards towards the umbilicus. It moves with respiration, since it is attached to the liver.

Obstruction of the bile-duct, apart from stone, is often due to occlusion of this canal by pressure of malignant growths, especially those commencing in the pylorus or pancreas. It is also seen following ulceration of the duct, cicatricial contraction of the scar tissue taking place. Enormous distension, both of the bile-duct itself and of its radicles in the liver substance, may occur at times.

Cholecystography (Pl. XXX).—The gall-bladder is not opaque to X-rays. If certain dyes (e.g. sodium tetraiodo-phenolphthalein) are given by the mouth or injected intravenously, they are excreted by the liver from the blood into the bile. In the gall-bladder the dye is concentrated and thus becomes opaque to X-rays. In this way the form, position and emptying process of the gall-bladder can be demonstrated radiographically. By this means it has been shown that the position and form of the gall-bladder vary with the type of body-build of the individual; in broad types (hypersthenic) the gall-bladder is broad and lies high up and far laterally (opposite the first lumbar vertebra), whereas in narrow types (asthenic) it is narrow, lies nearer the vertebral column and may reach as low as the fourth lumbar vertebra (F. Davies, 1927, *Brit. Med. Journ.*, 1, 1138).

THE UROGENITAL SYSTEM

The urogenital apparatus consists of (a) the urinary organs for the secretion and discharge of the urine, and (b) the genital organs, which are concerned with the process of reproduction. The two groups are included in one system because, in the male, they are not entirely independent of one another, since one passage (*viz.* the urethra) serves to convey both the urine and the seminal fluid.

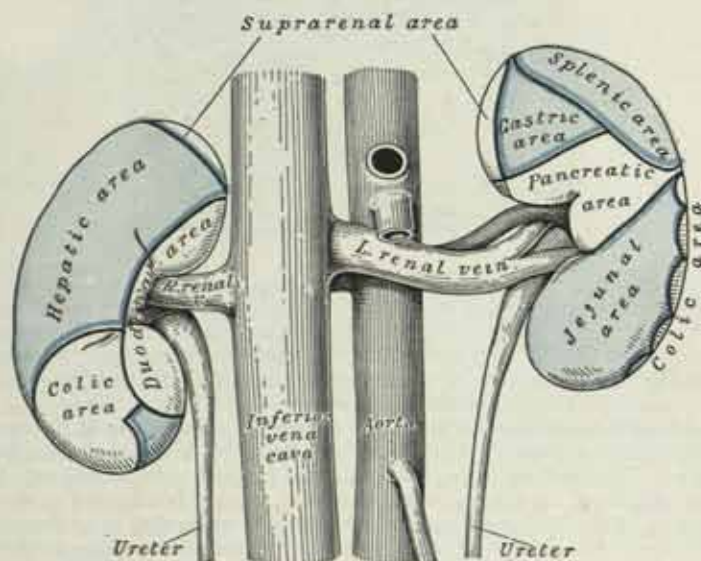
THE URINARY ORGANS

The urinary organs comprise (1) the *kidneys*, which secrete the urine; (2) the *ureters*, which convey it to (3) the *urinary bladder*, where it is stored temporarily; and (4) the *urethra*, through which it is discharged from the urinary bladder.

THE KIDNEYS [RENES]

The **kidneys** are two reddish-brown organs situated in the posterior part of the abdomen, one on each side of the vertebral column, behind the peritoneum; they are surrounded by a mass of fat and some loose areolar tissue. Their upper ends are on a level with the upper border of the twelfth thoracic vertebra, their

FIG. 1218.—The anterior surfaces of the kidneys, showing the areas related to neighbouring viscera.



lower, with the third lumbar vertebra. The right kidney is usually slightly lower than the left, probably on account of its relationship to the liver; the left is a little longer and narrower than the right and is a little nearer to the median plane. The long axis of each kidney is directed downwards and laterally; the transverse axis, laterally and backwards. The transpyloric plane (p. 1398) passes through the upper part of the hilus of the right kidney, and through the lower part of the hilus of the left.

Each kidney is about 11 cm. in length, 6 cm. in breadth, and about 3 cm. in thickness. In the adult male the weight of the kidney varies from 125 gm. to 170 gm.; in the adult female from 115 gm. to 155 gm. In a spare individual with a lax abdominal wall the lower pole of the kidney may just be felt in full inspiration by bimanual examination of the loin. Usually, however, it is impalpable. Its outline

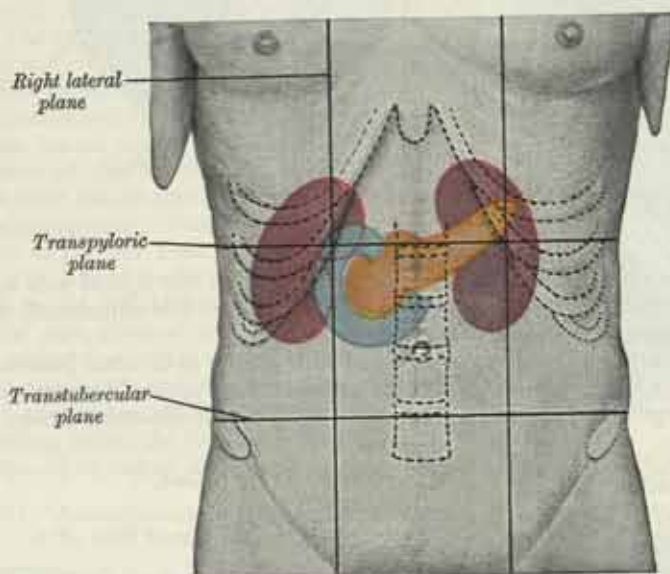
can be projected to the surface by drawing a kidney-shaped figure (fig. 1219) with the hilus 5 cm. from the median plane on the transpyloric plane or opposite the lower border of the first lumbar spinous process. As the kidney lies obliquely the width of the figure should be 1.5 cm. less than the actual width of the viscus.

The kidney has a characteristic shape, often described as bean-shaped, and presents for examination two surfaces, two borders, and an upper and a lower end.

Relations.—The *anterior surface* (figs. 1205, 1218) of each kidney is convex, and looks forwards and laterally. Its relations to adjacent viscera differ on the two sides of the body.

(a) *Anterior surface of right kidney.*—A narrow portion at the upper extremity is in contact with the right suprarenal gland. The gland may overlap the upper pole, or the upper part of the medial border, or it may occupy a position midway between the two. A large area just below this and involving about three-fourths of the

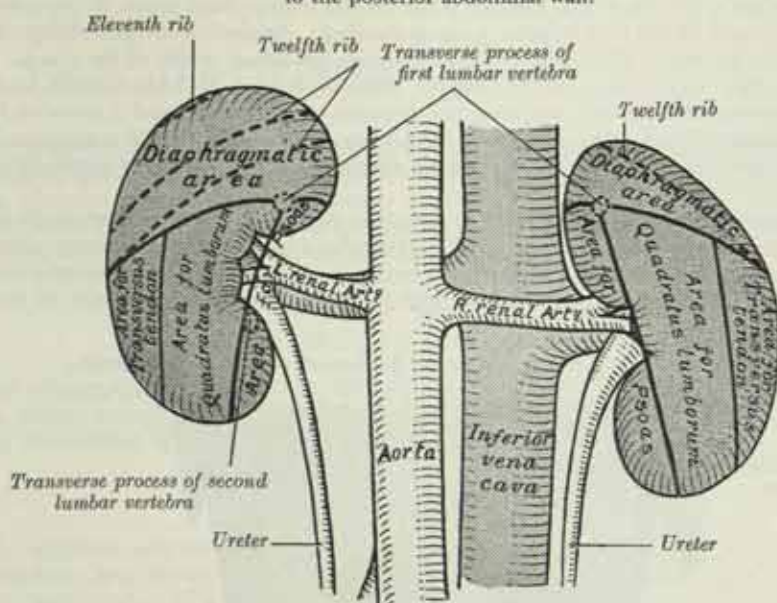
FIG. 1219.—The surface relations of the duodenum, pancreas and kidneys.



surface, lies in the renal impression on the right lobe of the liver, and a narrow but somewhat variable area near the medial border is in contact with the second part of the duodenum. The lower part of the anterior surface is in contact laterally with the right colic flexure, and medially, as a rule, with a part of the small intestine. The area in relation with small intestine and almost the whole of the area in contact with the liver are covered with peritoneum (with the intervention of the renal fascia); the suprarenal, duodenal and colic areas are devoid of peritoneum.

(b) *Anterior surface of left kidney.*—A small area along the upper part of the medial border is in relation with the left suprarenal gland, and the upper two-thirds or less of the lateral half of the anterior surface are in contact with the renal impression on the spleen. A somewhat quadrilateral field, about the middle of the anterior surface, is in contact with the body of the pancreas and the splenic vessels. Above this there is a small triangular portion, between the suprarenal and splenic areas, which is in contact with the stomach. The size of the gastric area is very variable. It is diminished, or may even be absent, when the left kidney lies at an abnormally low level, or when the obliquity of the body of the pancreas is accentuated. Below the pancreatic and splenic areas the lateral part is in relation with the left colic flexure and the commencement of the descending colon, and the medial part with the first coils of the jejunum. The jejunal area is always extensive but, as the descending colon is normally in a condition of contraction, the colic area forms an irregular, narrow strip immediately adjoining the lateral border of the kidney. The area in contact with the stomach is covered with the peritoneum of the omental bursa, while those in relation to the spleen and the jejunum are covered with the

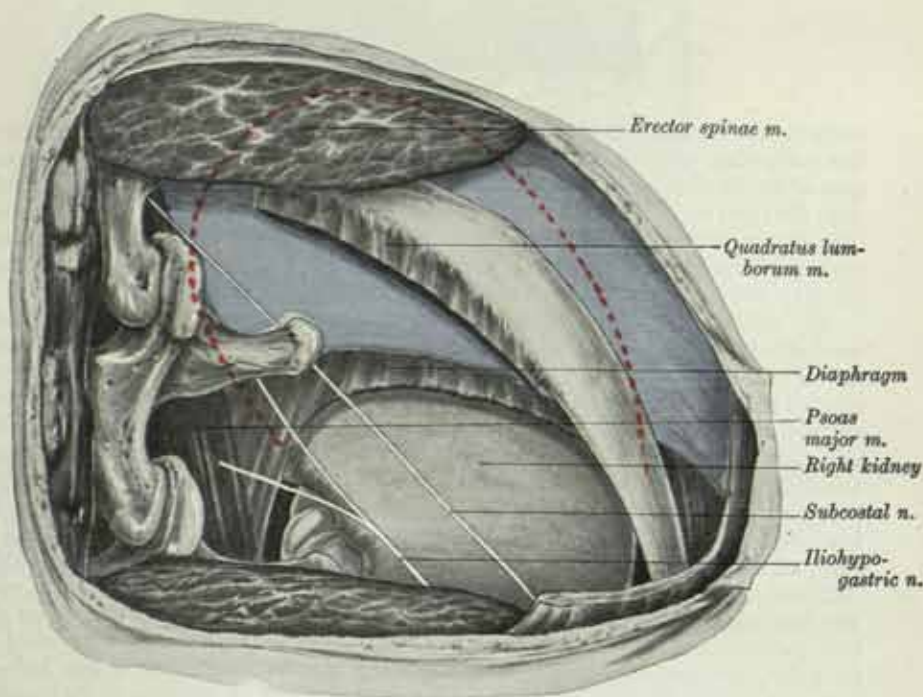
FIG. 1220.—The posterior surfaces of the kidneys, showing the areas of relation to the posterior abdominal wall.



peritoneum of the greater sac; behind the peritoneum of the jejunal area some branches of the left colic vessels are related to the kidney. The suprarenal, pancreatic, and colic areas are devoid of peritoneum.

The *posterior surface* (figs. 1220 to 1223) of each kidney is directed backwards and medially. It is imbedded in areolar and fatty tissue, and is devoid of peritoneal covering. It lies upon the Diaphragm, the medial and lateral lumbocostal arches, the

FIG. 1221.—The right kidney, exposed from behind.



The blue area represents the pleura, the broken red line the upper part of the kidney.

Psoas major, the Quadratus lumborum, and the tendon of origin of the Transversus abdominis, the subcostal vessels, and the last thoracic, iliohypogastric and ilioinguinal nerves. The right kidney rests upon the twelfth rib, the left usually on the eleventh and twelfth. The Diaphragm separates the kidney from the pleura, which dips down to form the costodiaphragmatic recess (fig. 1221), but sometimes the muscular fibres of the Diaphragm are defective or absent over a triangular area immediately above the lateral lumbocostal arch, and when this is so the perinephric areolar tissue is in contact with the diaphragmatic pleura.

The *upper end* of the kidney is thick and round, and is nearer the median plane than the lower; it is surmounted by the suprarenal gland, which covers also a small portion of the anterior surface. The *lower end*, smaller and thinner than the superior, extends to within 5 cm. of the iliac crest.

The *lateral border* is convex; that of the left kidney is, at its upper part, covered with greater sac peritoneum which separates it from the spleen and, at its lower part, it is in contact with the descending colon; the lateral border of the right kidney is separated by peritoneum of the greater sac from the right lobe of the liver.

FIG. 1222.—A sagittal section through the posterior abdominal wall showing the relations of the renal fascia. (After Gerota.)

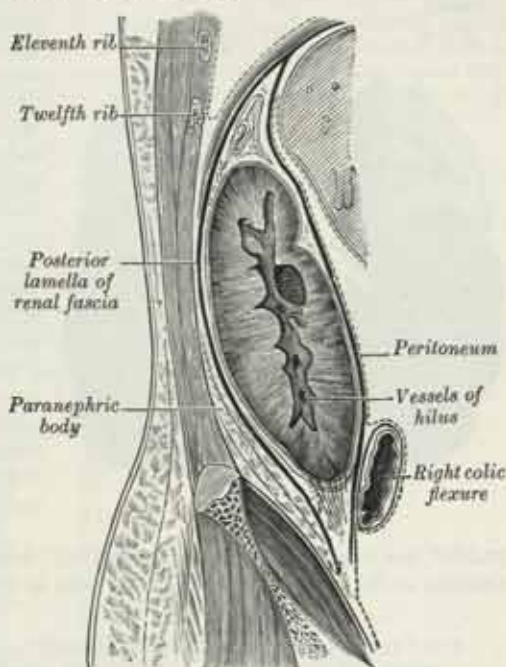
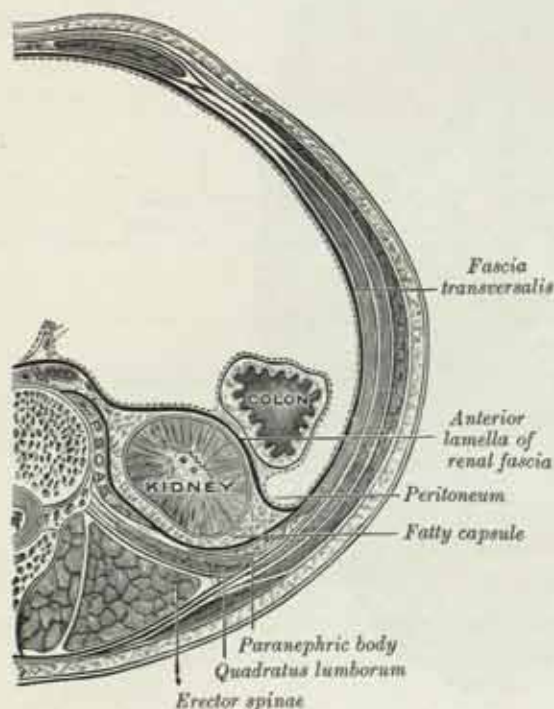


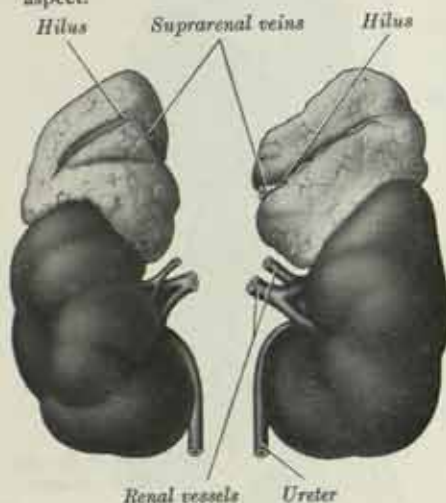
FIG. 1223.—A transverse section, showing the relations of the renal fascia. (After Gerota.)



The *medial border* is concave in the centre and convex at each end; it slopes downwards and laterally. In its central part there is a deep vertical fissure opening forwards and medially, termed the *hilus*, which is bounded by an anterior and a posterior lip, and transmits the renal vessels and nerves and the funnel-shaped upper end (*pelvis*) of the ureter. The relative positions of the main structures in the hilus are as follows; the renal vein is in front, the renal artery in the middle and the pelvis of the ureter behind. As a rule one of the branches of the renal artery enters the hilus behind the ureteral pelvis, and it is not uncommon to find one of the tributaries of the renal vein issuing from the hilus in the same plane. Above the hilus the medial border is in relation with the suprarenal gland, below with the commencement of the ureter.

The hilus leads into a central recess or cavity named the *renal sinus*, which is lined by a continuation of the capsule of the kidney and is almost entirely filled by the ureteral pelvis and renal vessels; numerous nipple-like elevations, termed the *renal papillæ*, mark the wall of the sinus. Just outside the hilus the ureter becomes dilated and its size increases progressively inside the sinus. This upper expanded portion is termed the *pelvis of the ureter*. Within the sinus it divides into two, sometimes three, large branches, which are named the *major calyces*, and each of these divides again into several short branches, named the *minor calyces* (fig. 1225). In all, there are usually from seven to thirteen of these minor calyces; each expands as it approaches the wall of the renal sinus, and the expanded end is indented and moulded round from one to three renal papillæ (Pl. XXXI). The wall of the expanded end of the calyx is firmly adherent to the capsule lining the renal sinus; it is perforated by the collecting tubules which open on the summits of the renal papillæ.

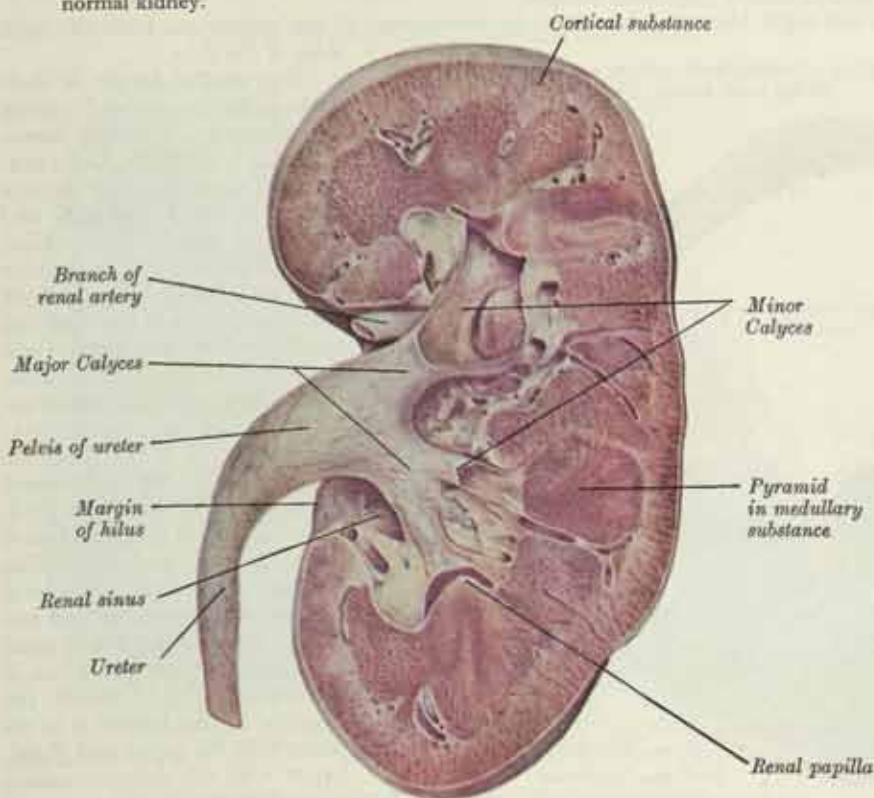
FIG. 1224.—The kidneys and suprarenal glands of a new-born child. Anterior aspect.



The kidney and its vessels are imbedded in a mass of fatty tissue, termed the *perirenal fat* or *adipose capsule*, which is thickest at the borders of the kidney and is prolonged through the hilus into the

The kidney and its vessels are imbedded in a mass of fatty tissue, termed the *perirenal fat* or *adipose capsule*, which is thickest at the borders of the kidney and is prolonged through the hilus into the

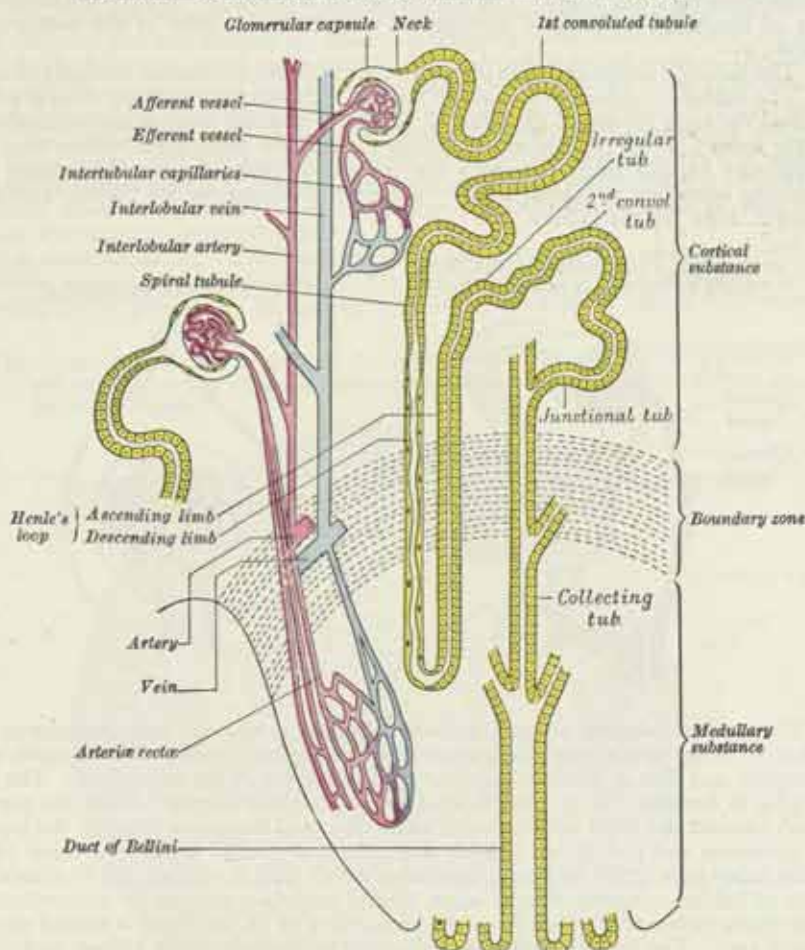
FIG. 1225.—A longitudinal section through a kidney, to show the pelvis of the ureter and its subdivision into calyces, and the characteristic appearance of the normal kidney.



renal sinus. The fibroareolar tissue surrounding the kidney and the renal fat is condensed to form a sheath and is termed the *renal fascia* (fig. 1223).

At the lateral border of the kidney the two layers of the sheath are fused. The anterior layer is carried medially in front of the kidney and its vessels, and at the level of the latter it merges with the connective tissue around the aorta and inferior vena cava. This continuation medially is very thin and does not extend higher than the superior mesenteric artery. The posterior layer extends medially behind the kidney and in front of the fascia on the Quadratus lumborum and Psoas major, and is attached to that fascia at the lateral and medial borders of the Psoas, and to the vertebrae and intervertebral discs. There is also a deeper stratum (not shown in fig. 1223)

FIG. 1226.—A scheme of a renal tubule and its vascular supply.



attaching the anterior and posterior layers to one another at the medial border of the kidney and pierced by the renal vessels.* This deeper stratum accounts for the fact that a perirenal effusion of fluid does not extend across to the opposite perirenal space. Above the suprarenal gland the two layers of the renal fascia fuse, and are connected with the fascia of the Diaphragm; below the kidney they remain separate, enclosing the ureter, the anterior layer being gradually lost in the extraperitoneal tissue of the iliac fossa, while the posterior layer blends with the fascia over the Iliacus muscle. Mitchell,† however, maintains that the anterior and posterior layers fuse below the kidney, though this fusion is weaker than that of the two layers above the suprarenal gland. The renal fascia is connected to the fibrous capsule of the kidney by numerous trabeculae, which traverse the fatty capsule, and are strongest near the lower end of the organ. Behind the renal fascia there is a considerable quantity of fat, which is sometimes termed the *paranephric body*. The kidney is held in position partly through

* C. P. Martin, *J. Anat.*, 1942, 77, 101.

† G. A. G. Mitchell, *Brit. J. Surgery*, 1950, 37, 257.

the attachments of the renal fascia and by the renal fat, but principally by the apposition of the neighbouring viscera.

In the fœtus the kidney consists of about twelve distinct lobules (fig. 1224), but in the adult these are fused and the kidney presents a uniformly smooth surface, though traces of the fœtal lobulation may remain.

General structure of the Kidney.—The kidney is invested by a thin transparent capsule, that is easily stripped off and consists of white fibrous tissue, with a few yellow elastic and smooth muscle fibres. In some diseases of the kidney the capsule becomes adherent to the kidney and cannot be readily stripped away.

If a vertical section be made from its lateral to its medial border, and the loose tissue and fat removed from around the vessels, pelvis of the ureter and the calyces, the *renal sinus* will be seen surrounded at all parts except the hilus by the proper kidney-substance (fig. 1225). The fibrous capsule is prolonged into the sinus round the lips of the hilus, to become continuous with the outer coat of the pelvis of the ureter.

The kidney is composed of an internal, medullary and an external, cortical substance.

The *medullary substance* consists of eight to eighteen pale, striated, conical masses, termed the *renal pyramids*, the bases of which are directed towards the circumference of the kidney, while their apices converge towards the renal sinus, where they form prominent papillæ projecting into the interior of the calyces, each minor calyx receiving from one to three papillæ. Each pyramid, capped by cortical substance, forms a 'lobe' of the kidney.

FIG. 1227.—The distribution of the blood-vessels in the cortex of kidney.

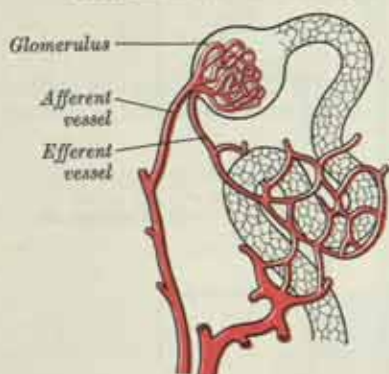


FIG. 1228.—A glomerulus.



The *cortical substance* is reddish-brown in colour, and soft and granular in consistence. It lies immediately beneath the fibrous capsule, arches over the bases of the pyramids, and dips in between adjacent pyramids towards the renal sinus. The parts dipping in between the pyramids are named the *renal columns*, while the portions which connect the renal columns with each other and intervene between the bases of the pyramids and the fibrous capsule are called the *cortical arches* or *cortical lobules*. If this latter part of the cortex be examined with a lens, it will be seen to consist of a series of lighter-coloured, conical areas, termed *medullary rays*, and a darker-coloured intervening substance, which from the complexity of its structure is named the *convoluted part*. The rays gradually taper towards the capsule of the kidney, and consist of a series of outward prolongations from the base of each renal pyramid.

Minute Anatomy.—The kidney is composed of a very large number of tortuous, closely-packed, tubules called the uriniferous tubules, bound together by a connecting stroma. Each tubule consists of two parts, which are embryologically distinct (p. 208), namely (1) the *nephron* or secreting part, which elaborates the urine, and (2) a *collecting tubule*. The *nephron* comprises (1) the *renal corpuscle*, which is concerned with filtration of substances from the plasma; (2) the *renal tubule*, which is concerned with the selective resorption of substances from the glomerular filtrate until it reaches the composition of urine. The *collecting tubule* carries the urine from a number of renal tubules to a *duct of Bellini*; the latter opens into a minor calyx at the apex of a renal papilla. If the surface of one of the papillæ be examined with a lens, it will be seen to be studded over with minute openings, the orifices of the ducts of Bellini, from sixteen to twenty in number, and if pressure be made on a fresh kidney, urine will be seen to exude from these orifices. The *renal (Malpighian) corpuscles*, which are small rounded masses of a deep red colour, averaging about 0.2 mm. in diameter, are found in the convoluted substance of the cortex and the renal columns. There

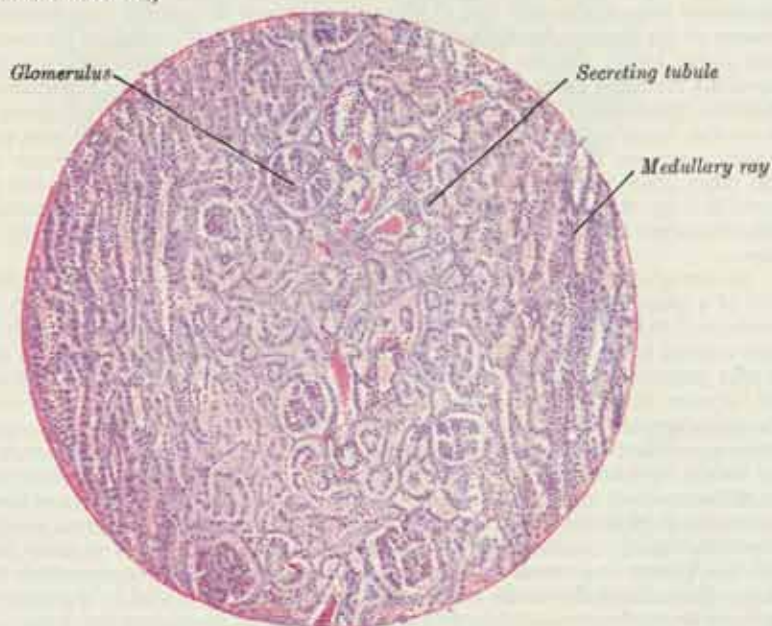
are between one million and four million renal corpuscles in each kidney. Each of these bodies is composed of two parts: a central *glomerulus* of vessels, and a membranous envelope, termed the *glomerular capsule*, which is the small pouch-like commencement of a renal tubule.

The *glomerulus* is a lobulated tuft of convoluted, capillary blood-vessels, held together by scanty connective tissue. This capillary network is derived from a small arterial twig (the *afferent vessel*), which enters the capsule, generally at a point opposite to that at which the latter is connected with the tubule; the *efferent vessel* emerges from the capsule at the same point, which is thus known as the vascular pole of the capsule.

The *glomerular capsule* is the blind, expanded end of the renal tubule, indented for the reception of the glomerulus. It consists of a basement-membrane, lined by a single layer of flattened epithelial cells. Thus between the glomerulus and the outer layer of the capsule there is a space lined by a continuous layer of flattened cells; this cavity varies in size according to the state of secretion and the amount of fluid present in it. In the foetus the lining epithelial cells are polyhedral or columnar. The blood in the capillaries is separated from the capsular space, not only by the capillary endothelium, but also by flattened epithelium and a basement membrane (the invaginated wall of the capsule), and the glomerular filtrate from the capillaries passes through these three layers, which collectively form a very thin membrane. Electron microscope studies show that it is only the basement membrane which forms a continuous structure, there being minute pores between the capillary endothelial cells and between the capsular epithelial cells.*

Each *renal tubule* (fig. 1226) consists of the following parts in sequence: (1) the *glomerular capsule*, already described; (2) the *proximal* (or first) *convoluted tubule*, connected to the glomerular capsule by a short *neck* (which in man is only slightly

FIG. 1229.—Radial section through the renal cortex. Stained with hæmatoxylin and eosin. $\times \bar{c} 120$. (Drawn from a preparation kindly lent to the Editors by Dr. E. E. Hewer.)



narrower than the rest of the tubule); the terminal part of the convoluted tubule becomes narrow and straight or slightly spiral (*spiral tubule*) and runs towards the medulla; (3) the *descending limb of the loop of Henle*, which runs into a medullary pyramid, where it turns to form (4) the *loop of Henle*, which is continued as (5) the *ascending limb of the loop of Henle*, which is broader than the descending limb and, passing up the pyramid, re-enters the cortical substance to be continuous with (6) the *distal* (or second) *convoluted tubule*, that finally straightens out as (7) the *junctional tubule*, which ends by joining a *collecting* or *straight tubule*. Between the distal convoluted tubule and the junctional tubule, there is a short angular segment of the renal tubule that is called the *zig-zag* (or *irregular*) *tubule*.

* D. Pease, *Anat. Rec.*, 1955, 121, 701; *J. Histol.*, 1955, 3, 295.

The *straight or collecting tubules* commence in the medullary rays of the cortex; they unite at short intervals with one another; the terminal tubes present a considerable increase in calibre, and are known as the *ducts of Bellini*; they open finally on the summit of a papilla, the (16 to 20) duct openings giving the tip of the papilla a cribriform appearance (*area cribrosa*).

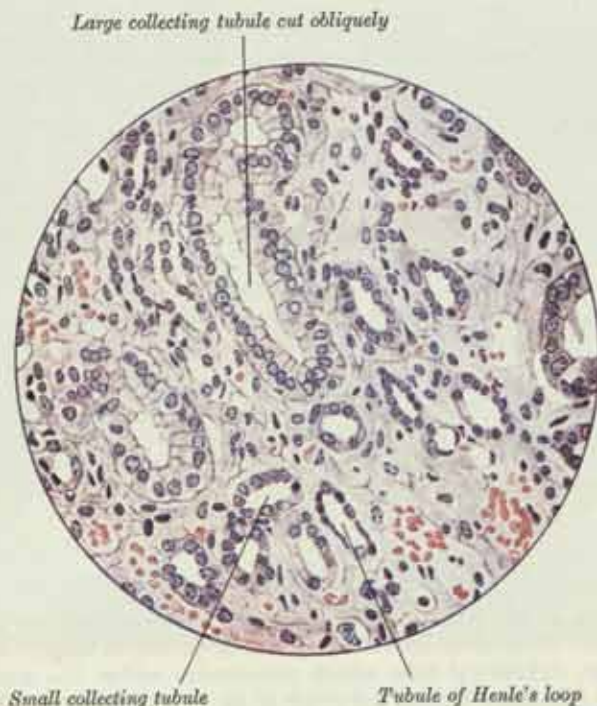
Structure of the renal tubules.—The renal tubules are lined by a single layer of epithelial cells, outside which there is a basement membrane. The epithelium varies in the different parts of the tubule. In the proximal convoluted tubule, which is about 60μ in diameter, the cells have the appearance of tall truncated cones with their narrow ends towards the lumen of the tubule, though the cells become flattened if the tube is distended with glomerular filtrate. Their cytoplasm stains deeply with eosin and the linear arrangement of the rod-like mitochondria in the basal part of the cells gives the cytoplasm a striated appearance. The large spherical nuclei are situated in the basal part of the cells. The cells, like those lining the small intestine, have a striated border (brush border), which indicates that the cells have considerable absorptive (resorptive) functions. These borders contain alkaline phosphatase, an enzyme that is concerned in the absorption of glucose, and normally all the glucose of the glomerular filtrate is resorbed into the blood-stream by the proximal convoluted tubules. Water is also resorbed, and other enzymes present are concerned in the resorption of other materials. The glomerular filtrate in the glomerular capsule has the same composition as blood plasma, with the exception of large molecules like proteins and fats, and it is formed by the glomerulus acting as an ultrafilter due to the hydrostatic pressure in the capillaries. The relatively high pressure in the glomerular capillaries has been attributed to the efferent vessel being narrower than the afferent vessel (figs. 1227, 1228), though some maintain that these vessels have the same diameter and that the effect is produced through the agency of contractile cells in the wall of the efferent vessel. The descending limb of Henle's loop is thin, being about 15μ in diameter, and the lining cells are flat with their nuclei bulging towards the lumen. The ascending limb is thicker (about 30μ in diameter) and the lining cells are cuboidal. The blood in the capillaries around the limbs of the loop of Henle has previously passed through the glomeruli, in which it became concentrated by the passage of the glomerular filtrate. Thus, owing to the difference in the osmotic pressure of the blood and the contents of the tubule, water passes back into the blood, especially from the descending limb, the wall of which is so thin. Compared with the proximal convoluted tubule, the distal convoluted tubule is slightly thinner ($30-40\mu$), but as the lining cells are flatter the lumen is somewhat wider; the lining cells do not possess a striated border and the cytoplasm is not so eosinophilic. Water absorption also takes place from this part of the tubule and it is believed that the process is controlled by the antidiuretic hormone of the posterior lobe of the pituitary gland; some maintain that this hormone controls water absorption from the limbs of Henle's loop.

As stated above, the afferent and efferent vessels of a glomerulus join the vascular pole of a glomerular capsule more or less opposite the site of origin of the proximal convoluted tubule (figs. 1227, 1228). In each nephron, the ascending limb of Henle's loop returns from the medulla and passes towards the glomerulus which gave origin to that particular nephron, and the commencement of the distal convoluted tubule lies between the afferent and efferent vessels at the vascular pole, in close contact with the vascular pole and the afferent vessel. Between the tubule and the vascular pole there is a collection of small cells that constitute what is known as the macula densa, the nature and function of which are not known. The cells of the tunica media of the afferent vessel in this region differ from the unstriated muscle fibres of blood vessels in general in that they are large, rounded and 'epithelioid' in type and have large spherical nuclei; as revealed by special stains their cytoplasm is granular. These cells are known as juxtaglomerular cells and they lie in close contact with the macula densa, the cells of the distal convoluted tubule, and the blood in the afferent vessel. In experimental animals in which the blood supply to the kidney has been diminished, with consequent increase of blood pressure, and in some patients with hypertension associated with kidney disease, the juxtaglomerular cells have been found to be hypertrophied and increased in number. In these conditions it is believed by some that the juxtaglomerular cells produce an enzyme (renin) which converts a protein (hypertensinogen) in the blood to a polypeptide (hypertensin), and that the latter substance is responsible for the increase in blood pressure. The precise role of the juxtaglomerular cells in relation to hypertension is, however, not definitely established.

The renal blood-vessels (fig. 1226).—Before entering the kidney, each artery divides into four or five branches which at the hilus lie mainly between the renal vein and the pelvis of the ureter, the vein being in front, the pelvis behind; one branch usually lies behind the pelvis. Each vessel gives off some small branches to the suprarenal glands, to the ureter, and to the surrounding cellular tissue and muscles. One or two *accessory renal arteries* may arise from the abdominal aorta, either above

or below the renal artery. Such vessels do not enter the hilum, but pierce the upper or lower parts of the kidney. The branches of the renal artery, while in the sinus, give off a few twigs for the nutrition of the surrounding tissues, and divide into *lobar arteries*, one for each renal papilla. Before entering the kidney-substance each lobar artery divides into two (sometimes three) *interlobar arteries* which run towards the cortex on each side of the pyramid. At the junction between the cortex and the medulla each interlobar artery divides dichotomously into branches which run at right angles to the parent stem. These are termed the *arcuate arteries*, and it is to be noted that the interlobar and arcuate arteries to each lobe do not anastomose with the corresponding arteries of neighbouring lobes. The arcuate arteries give off a large number of straight arteries [*interlobular*], arranged vertically to the surface, each of which

FIG. 1230.—A transverse section through a pyramid of a human kidney. Stained with hæmatoxylin and eosin. $\times 400$.



gives off a number of lateral branches, afferent vessels of the glomeruli, or *glomerular arteries*. In injected specimens which have been cleared each interlobular artery with its branches and associated glomeruli resembles a string of red currants.

From the capillaries of each glomerulus, except those adjacent to the medulla, an efferent vessel arises and divides to form a second set of capillaries which run between the tubules and are called *intertubular capillaries*. These unite to form *interlobular veins*, which discharge into the tributaries of the *interlobar veins* running with the interlobar arteries. Each interlobular vein begins beneath the fibrous capsule of the kidney by the convergence of smaller veins, called *stellate veins* because of their appearance as seen from the surface of the organ.

The vascular supply of the medulla of the kidney is derived from the efferent vessels of the glomeruli adjacent to the medullary substance. These efferent vessels are larger than those from the glomeruli at the periphery of the cortex and many of them divide into vessels, the *straight arterioles*, which, passing into the medulla, run a straight course closely related to the thin-walled descending limbs of the loops of Henle. The other branches of the efferent vessels from the juxtamedullary glomeruli break up into intertubular capillaries, like the efferent vessels from the glomeruli in the outer part of the cortex. Veins from the medulla enter the arcuate veins and so reach the interlobular veins which unite to form the renal vein.

The circulation through the kidney is primarily a glomerular circulation, and all the branches which arise from the arcuate and interlobular arteries terminate in

glomeruli.* Normally the renal blood circulates more plentifully through the cortex than through the medulla, but in certain circumstances the cortical vessels may become constricted and the vessels passing to the juxtamedullary glomeruli dilated.† This is known as the 'renal shunt mechanism' and it results in nearly all the blood entering the kidney being shunted through the juxtamedullary glomeruli (which are relatively few in number) to the medulla, the cortex receiving very little blood. As a consequence, the amount of urine produced is considerably diminished and even anuria may occur. Such a condition may be brought about by, for example, severe crushing injuries ('crush syndrome'), and is due to the reflex contraction of the cortical vessels.

The kidney is divided into five vascular segments ‡; the apical segment occupies the medial side and anterior part of the upper pole, the lower segment forms the lower pole, the upper (anterior) segment includes the upper pole and part of the central area, the middle (anterior) segment lies between the upper (anterior) and the lower segments, and the posterior segment includes the entire posterior part of the kidney between the apical and lower segments. Each segment is supplied by a separate branch of the renal artery and there is no anastomosis between adjoining segments.

In the living subject a pale streak, known as Brödel's line, marks the dorsal part of the lateral convex border of the kidney and indicates on the surface of the organ the boundary zone between the areas of distribution of the anterior and the posterior branches of the renal artery.

Nerves of the kidney.—The nerves of the kidney are described on p. 1217.

The *lymph vessels* of the kidney are described on p. 906.

Connective tissue, or intertubular stroma.—Although the tubules and vessels are closely packed, a small amount of connective tissue, continuous with the fibrous capsule, binds them firmly together and supports the blood-vessels, lymph vessels and nerves.

Applied Anatomy.—Incisions into the kidney for the purpose of displaying the interior of the pelvis of the ureter are made along Brödel's line. The plane of the incision passes through the relatively avascular area and undue hæmorrhage is thus avoided.

The early pelvic position of the kidney (p. 208) may persist, and in these cases the organ usually derives its blood-supply from the common iliac artery, and the hilus lies on its anterior aspect. 'Disc kidney' and 'horseshoe kidney,' representing complete or partial fusion of the two organs, also occurs. Congenital absence, or imperfect development, of one kidney may occur, and may be compensated by enlargement of the kidney on the opposite side. Rarely the two kidneys may lie on the same side of the body.

THE URETERS

The **ureters** are the two tubes which convey the urine from the kidneys to the urinary bladder. Each measures from 25 cm. to 30 cm. in length, and is a thick-walled, narrow, cylindrical tube which commences within the renal sinus as a funnel-shaped dilatation, termed the *pelvis of the ureter* (fig. 1225). It runs downwards and slightly medially in front of the Psoas major, passes into the pelvic cavity, and opens into the base of the urinary bladder. Its position can be projected to the surface where it is represented by a line from a point on the transpyloric plane 5 cm. from the median plane drawn downwards and medially to the pubic tubercle.

The *pelvis of the ureter* has already been described (p. 1474).

The *abdominal part* of the ureter lies behind the peritoneum on the medial portion of the Psoas major, which intervenes between it and the tips of the transverse processes of the lumbar vertebræ (Pl. XXXI). On the Psoas major it crosses in front of the genito-femoral nerve and is itself crossed obliquely by the testicular (or ovarian) vessels. It enters the pelvic cavity by crossing in front of either the end of the common, or the beginning of the external, iliac vessels.

At its origin the *right ureter* is usually covered by the second part of the duodenum; in its course downwards it lies to the right of the inferior vena cava, and is crossed anteriorly by the right colic and the ileocolic vessels, while near the inlet of the pelvis it passes behind the lower part of the mesentery and the terminal part

* D. B. MacCallum, *American Journal of Anatomy*, 38, 1926. R. A. Moore, *Anatomical Record*, 40, 1928.

† "Studies of the Renal Circulation," J. Trueta, A. E. Barclay, P. M. Daniel, K. J. Franklin, M. M. L. Prichard, *Blackwell Scientific Publications*, 1947.

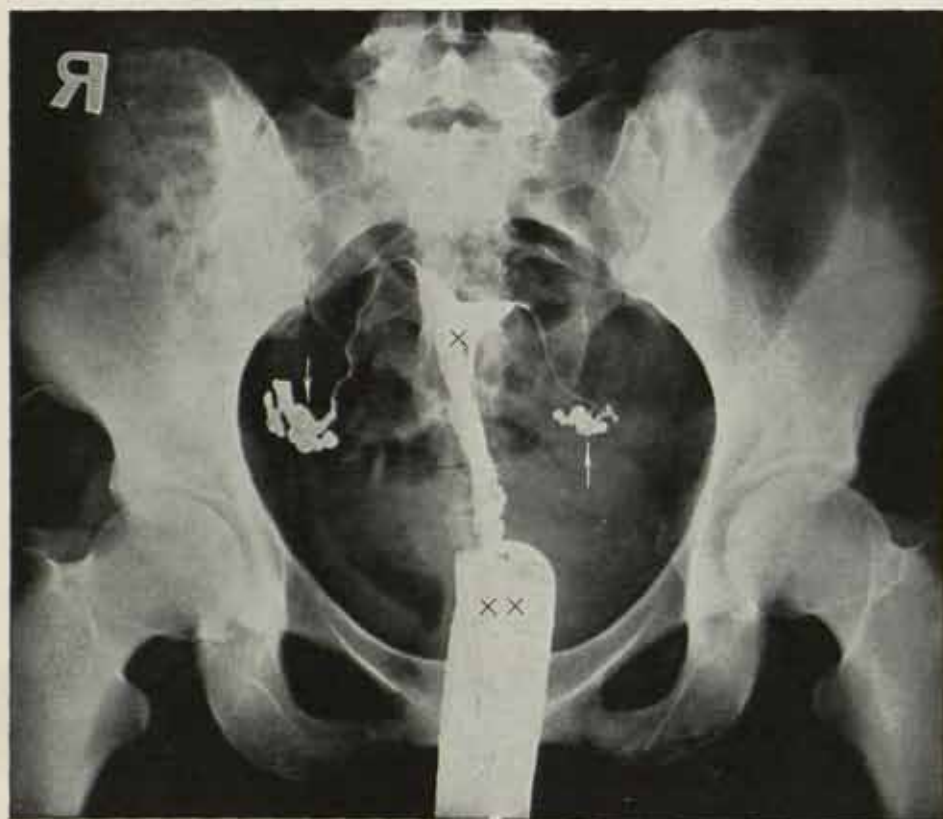
‡ F. T. Graves, *Brit. J. Surgery*, 1954, 42, 132.

PLATE XXXI



Radiograph of the lumbar vertebrae, after intravenous injection of uroselectan, **B**. Anterior view. The ureters and their pelves, and the major and minor calyces are well shown. Note the cupping at the extremities of the minor calyces. Note also the relation of the ureter to the transverse processes and that the lateral edge of the left Psoas major muscle can be recognised. The arrow points to the shadow of the right kidney.

PLATE XXXII



Radiograph of the genital tract in the female, after an injection of barium sulphate into the uterus.

X = body of uterus. Note the two cornua leading to the uterine tubes.

XX = speculum in vagina.

The arrows indicate the infundibula of the uterine tubes. Some of the barium has passed through the abdominal opening of the tube into the general peritoneal cavity.

of the ileum. The *left ureter* is crossed by the left colic vessels, and near the inlet of the pelvis passes behind the sigmoid colon and its mesentery, lying in the posterior wall of the intersigmoid recess.

The *pelvic part* of the ureter runs at first downwards on the lateral wall of the pelvic cavity, under cover of the peritoneum, and along the anterior border of the greater sciatic notch. It lies in front of the internal iliac artery and its anterior division, and medial to the obturator nerve and the umbilical, obturator, inferior vesical, and middle rectal arteries. Opposite the lower part of the greater sciatic foramen it runs medially and forwards, and reaches the lateral angle of the urinary bladder, where it is situated in front of the upper end of the seminal vesicle (and at a distance of about 5 cm. from the opposite ureter); here the ductus deferens crosses in front of it to gain its medial side (fig. 1233), and the vesical veins surround it. Finally, the ureters run obliquely through the wall of the bladder and open by slit-like apertures into the cavity of that viscus at the lateral angles of the trigone (fig. 1236). When the bladder is distended the openings of the ureters may be about 5 cm. apart, but when it is empty and contracted the distance between them is diminished by one-half. Owing to their oblique course through the coats of the bladder, the upper and lower walls of the terminal portions of the ureters become closely applied to each other when the bladder is distended, and, acting as valves, prevent regurgitation of urine. Regurgitation is prevented also by peristalsis of the ureteric muscle and by the presence of small, valve-like folds of mucous membrane at the entrance of the ureter into the bladder. It should be noted that the peritoneum is closely applied to the medial side of the pelvic part of the ureter (fig. 1232), except at its termination, where the ductus deferens and, sometimes, one or two small vessels intervene.

In the *female*, the pelvic part of the ureter forms the posterior boundary of a shallow depression named the *ovarian fossa*, in which the ovary is situated (fig. 1235). It runs medially and forwards below the lower part of the broad ligament of the uterus, and passes lateral to the supravaginal portion of the cervix uteri and above the lateral fornix of the vagina. It then lies for a short distance in front of the vagina, and finally pierces the wall of the bladder obliquely. In this part of its course it is accompanied for about 2.5 cm. by the uterine artery, which then crosses in front of the ureter and ascends between the two layers of the broad ligament. The ureter is distant about 2 cm. from the side of the cervix of the uterus.*

The ureter is sometimes duplicated on one or both sides, and the two tubes may remain distinct as far as the base of the urinary bladder; they rarely open separately into the bladder cavity. The ureter is slightly constricted at its upper end and where it crosses the brim of the pelvis; it is narrowest where it passes through the wall of the bladder.

The ureter, its pelvis and the calyces can be demonstrated in the living subject

* J. C. Brash (*British Medical Journal*, Oct. 28, 1922) says:

"The relation of the last portion of the ureter to the vagina is variable. There is usually a portion of the ureter in front of the vagina, lying for a short distance in the connective tissue between the vagina and bladder, and then in the wall of the bladder itself.

"With the vagina and bladder symmetrically related to each other this portion of the ureter is equal on the two sides; but deviation from the symmetrical position is the rule. The result is an increase of this portion of the ureter on one side and a corresponding decrease on the other. There is frequently no ureter in front of the vagina on one side, and therefore a much longer portion than usual on the other side.

"In the majority of specimens examined, it is the left ureter that has the greatest relation to the vagina, and it is occasionally found crossing the middle line of the vagina. . . . It must not be forgotten, however, that occasionally the position may be reversed."

FIG. 1231.—A transverse section through the lower third of the ureter. Stained with hæmatoxylin and eosin. $\times 20$.



by radiograms taken (1) after the intravenous injection of 'diodone,' which is excreted as a radio-opaque substance in the urine (descending or excretion pyelography); or (2) after injection of sodium iodide solution introduced into the ureter from below by means of a ureteric catheter passed through the operating cystoscope (p. 1489) (ascending or retrograde pyelography). The resulting photograph is termed a *pyelogram* (Pl. XXXI). The cupping of the minor calyces by the projecting renal papillæ should be noted as it may be absent in pathological conditions, e.g. hydronephrosis.

Structure (fig. 1231).—The ureter is composed of three coats: fibrous, muscular and mucous.

The *fibrous coat* is continuous at one end with the fibrous capsule of the kidney in the floor of the renal sinus: while at the other it is lost on the wall of the bladder.

The *muscular coat* in the pelvis, calyces and upper two-thirds of the ureter consists of two layers, an inner longitudinal and an outer circular. The longitudinal coat ends above at the attachment of the minor calyces to the renal papillæ. The circular muscle in this region becomes prominent and forms rings around the bases of the papillæ; the periodic contractions of this muscle may have the effect of 'milking' the papillæ and squeezing urine out of the ducts of Bellini. In the lower third of the ureter, an additional outer longitudinal muscular layer is added, and the inner longitudinal layer becomes less distinct. In its oblique passage through the wall of the bladder the muscle is arranged entirely in a longitudinal direction, and this, on contraction, has the effect of keeping patent this part of the ureter. The muscle coat of the ureter is not compactly arranged as in the intestine but is infiltrated by connective tissue derived from the mucous and fibrous coats. Furthermore, as in the case of the urinary bladder, the muscular coats described above intermingle to such an extent that they cannot be separated into three clearly defined strata. The muscular coat of the ureter undergoes peristaltic contractions progressing downwards from the pelvis and calyces; they propel jets of urine into the bladder at the rate of 4 or 5 times a minute.

The *mucous coat* is smooth, and presents about six longitudinal folds which become effaced by distension. It is continuous with the mucous membrane of the bladder below, while it is prolonged over the papillæ of the kidney above. It consists of fibrous tissue containing many elastic fibres, and covered with transitional epithelium, 4 or 5 cells thick in the ureter and 2 or 3 cells thick in the pelvis and calyces. No distinct submucosa is present.

The *arteries* supplying the ureter are branches from the renal, testicular (or ovarian), internal and common iliac and inferior vesical arteries. A good anastomosis exists between these arteries supplying different parts of the ureter.

The *lymph vessels* of the ureter are described on p. 906.

The *nerves* (p. 1217 and fig. 999) are derived from the renal, aortic, and superior and inferior hypogastric plexuses; through these plexuses fibres are derived from the lower three thoracic and first lumbar, and the second to the fourth sacral, segments of the spinal cord. Small ganglia and isolated ganglion-cells are found in the fibrous and muscular coats.

Applied Anatomy.—In *renal colic* pain is experienced in the cutaneous areas innervated from those segments of the spinal cord which also supply the ureter. It commences in the loin in the area supplied by the tenth thoracic nerve and shoots downwards and forwards to the groin, affecting in succession areas supplied by the eleventh and twelfth thoracic and the first lumbar nerves. Finally, it shoots into the testis of the same side. Irritation of the genitofemoral nerve, which supplies the cremaster muscle (p. 593), may cause contraction of the muscle and consequent retraction of the testis.

THE URINARY BLADDER [VESICA URINARIA]

The **urinary bladder** (fig. 1232) is a sac which acts as a reservoir for the urine; its size and position vary with the amount of fluid that it contains, and also with the state of distension of the neighbouring viscera. "The mean capacity of the living urinary bladder in the male adult is 220 c.c., varying from 120 c.c. to 320 c.c." * Commonly the bladder is emptied when it contains about half-a-pint of urine (284 c.c.).

When the empty bladder is firmly contracted, it presents the form of a flattened tetrahedron. It has a base or fundus, an apex, a superior and two inferolateral

FIG. 1232.—A median sagittal section through the male pelvis.

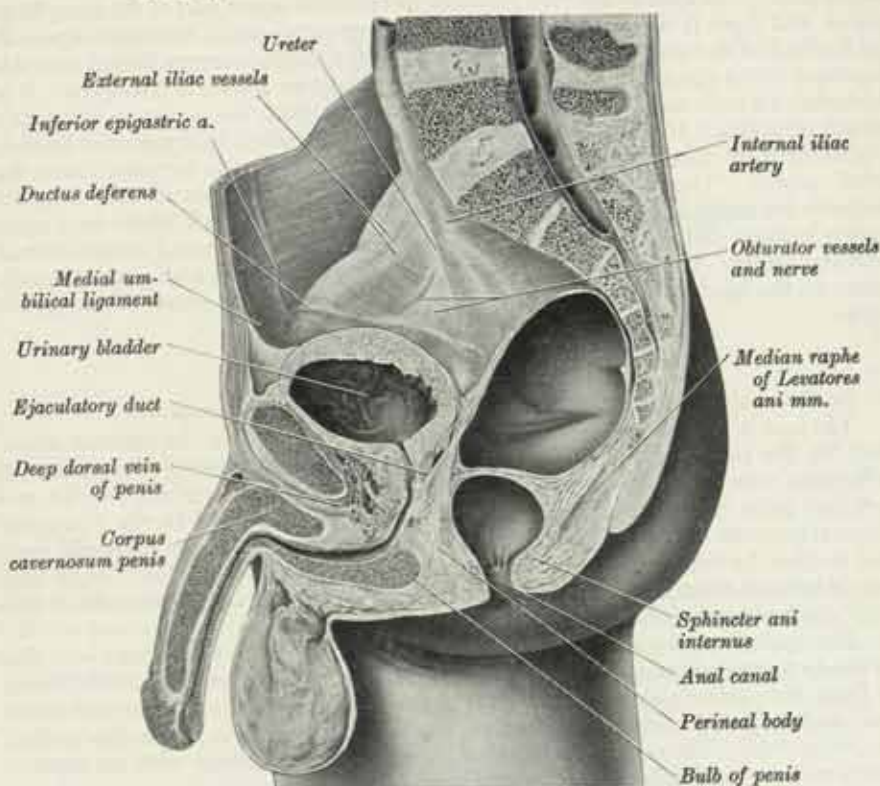
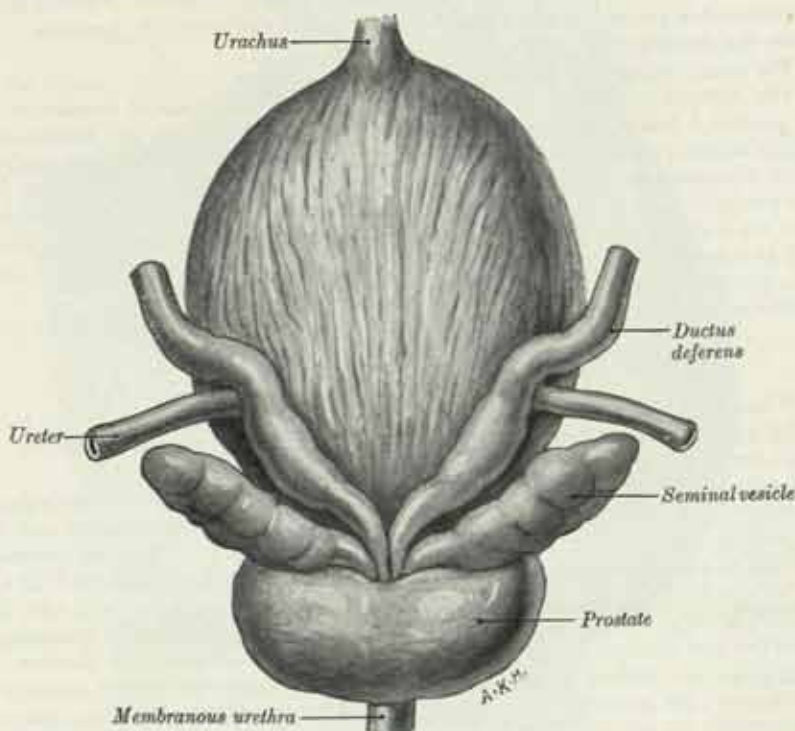


FIG. 1233.—The urinary bladder and prostate, viewed from above and behind.



surfaces and a neck. The *base* is triangular in shape, and is directed downwards and backwards. The *apex* is directed forwards towards the upper part of the symphysis pubis, and from it the median umbilical ligament (urachus) is continued upwards on the back of the abdominal wall to the umbilicus; the peritoneum folded over this ligament forms the median umbilical fold. The *superior surface* is triangular; it is bounded on each side by a lateral border (running from the ureter to the apex), which separates it from the inferolateral surface, and behind by a posterior border, represented by a line joining the two ureters, which intervenes between it and the basal aspect. The *inferolateral surfaces* are directed downwards and laterally towards the pubis and pelvic walls. In the male the *neck* of the bladder rests upon and is in direct continuity with the base of the prostate; it is pierced by the internal urethral orifice. It is subject to but little alteration in position with varying conditions of the bladder and rectum, and lies a little above the plane of the pelvic outlet.

RELATIONS OF THE EMPTY BLADDER

In the male (figs. 1232 and 1233).

The *base* is related to the rectum but is separated from it in the extreme upper part by the recto-vesical pouch of peritoneum (p. 1402). Below the peritoneal reflection, which is about 7.5 cm. from the anal orifice, the seminal vesicles and terminal parts of the deferent ducts separate the two viscera. In the triangular interval between the two deferent ducts, the bladder and rectum are separated from one another by the recto-vesical fascia only. The lower part of this triangle may be obliterated when, as often happens, the deferent ducts come into contact one with another some distance above the prostate.

The *superior surface* is covered completely with peritoneum continuous with that of the recto-vesical pouch behind and of the paravesical fossæ (p. 1404) at the sides; in front, the peritoneum passes on to the posterior surface of the anterior abdominal wall and, where it covers the median umbilical ligament, it forms the median umbilical fold. The superior surface of the bladder is in contact with the sigmoid colon and the terminal coils of the ileum.

The *infero-lateral surfaces*, anteriorly, are separated from the pubis and the pubo-prostatic ligaments by a mass of fatty tissue termed the *retro-pubic pad*; behind this they are separated by fascia from the Levator ani and Obturator internus muscles.

The *neck* is related to and fused with the upper surface of the prostate.

In the female (fig. 1235).

The *base* is related to the anterior wall of the vagina.

The *superior surface* is covered with peritoneum over most of its extent. Near the posterior border the peritoneum is reflected from it to the antero-inferior surface of the uterus at the level of the internal os (p. 1513). The peritoneal recess which separates the bladder from the uterus is termed the vesico-uterine pouch. The posterior part of the superior surface is devoid of peritoneum and is separated from the supravaginal portion of the cervix of the uterus by fibro-areolar tissue.

The *inferolateral surfaces* have relations the same as in the male except that the pubo-prostatic ligaments are replaced by the pubo-vesical bands.

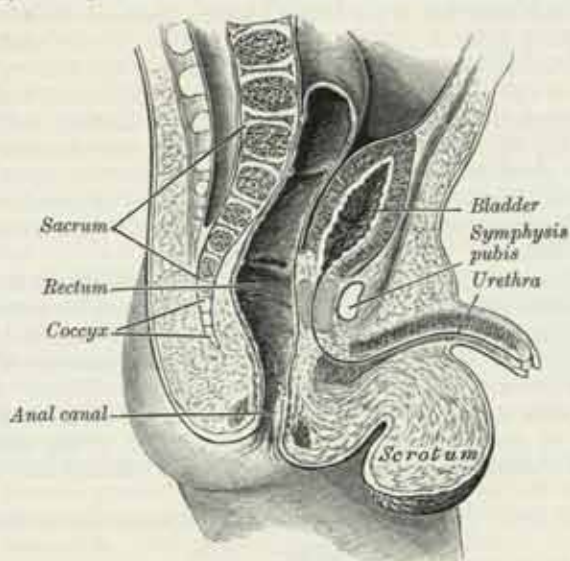
The *neck* is related to pelvic fascia which surrounds the first part of the urethra.

THE POSITION OF THE BLADDER

When the bladder is empty it is placed entirely within the pelvis, below the level of the obliterated umbilical arteries, and of the portions of the deferent ducts which are in contact with the lateral wall of the pelvis.

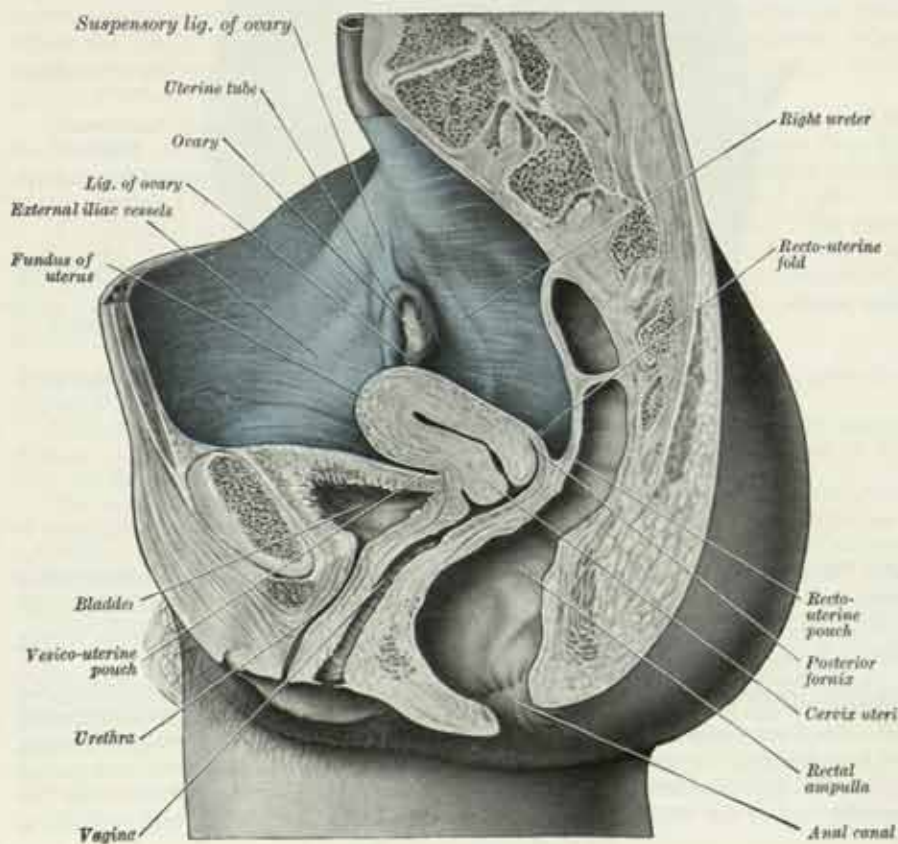
As the bladder fills, its superior surface gradually rises into the abdominal cavity, carrying with it its peritoneal covering, and at the same time rounding off and finally obliterating the posterior and lateral borders. When the bladder is distended it assumes an ovoid form, the long diameter being directed upwards and forwards. In this condition it presents a posterosuperior, an anteroinferior and two lateral surfaces, a base, and a summit; owing to the obliteration of the posterior and lateral borders the four surfaces are not sharply marked off from one another. The posterosuperior surface is directed upwards and backwards, and is covered with peritoneum; its posterior part is separated from the rectum by the recto-vesical pouch, while its anterior part is in contact with coils of the small intestine. The

FIG. 1234.—A sagittal section through the pelvis of a new-born male child.



antero-inferior surface is devoid of peritoneum, and rests against the pubic bones and the posterior surface of the anterior abdominal wall. The lower parts of the lateral surfaces are destitute of peritoneum, and are in contact with the lateral walls of the pelvis. The line of peritoneal reflection from the lateral surfaces is raised to

FIG. 1235.—A median sagittal section through the female pelvis. The peritoneum is shown in blue.

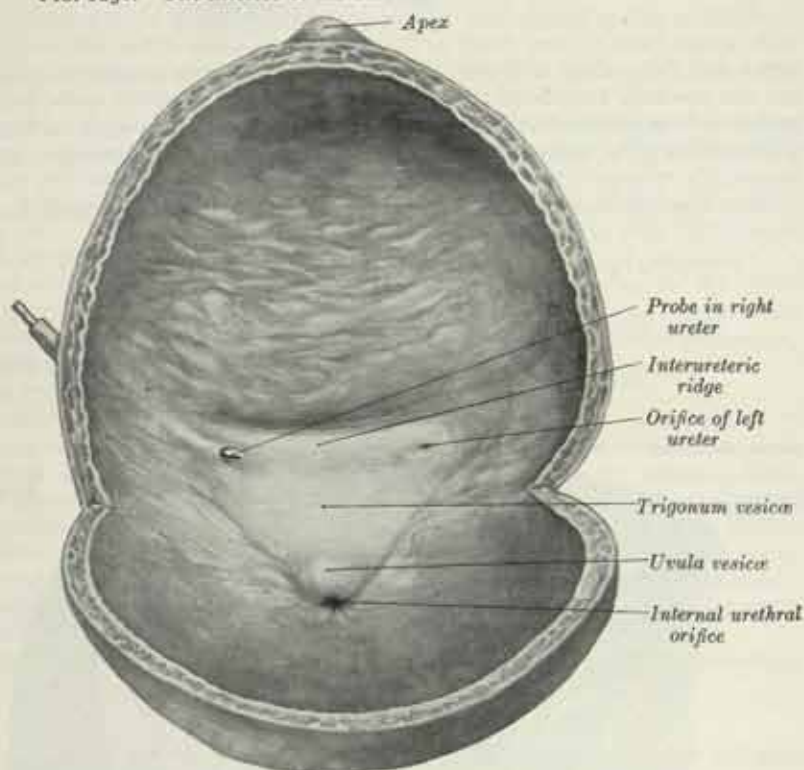


the level of the obliterated umbilical arteries. The base, being more or less fixed, has the same relations as that of the empty bladder, the level of peritoneal reflection from it undergoing little or no change. The summit of the bladder is directed upwards and forwards above the point of attachment of the median umbilical ligament, and hence the peritoneum, which follows the ligament, forms a pouch of varying depth between the summit and the anterior abdominal wall.

In the female, the full bladder raises the uterus into a more erect position (p. 1513). The posterosuperior surface is separated from the body and fundus of the uterus by the vesico-uterine pouch and below this is in contact with the cervix uteri and the upper part of the vagina. The relations of other surfaces are similar to those in the male.

In the new-born child (fig. 1234) the internal urethral orifice is at the level of the upper border of the symphysis pubis; the bladder therefore lies relatively at a much higher level in the infant than in the adult. Its anterior surface, devoid of peritoneum, "is in contact with about the lower two-thirds of that part of the abdominal wall which lies between the symphysis pubis and the umbilicus" (Symington *). Its postero-superior surface is clothed with peritoneum as far as the level of the internal orifice of the urethra. Although the bladder of the infant is usually described as an abdominal organ, Symington pointed out that only about one-half

FIG. 1236.—The interior of the bladder. Viewed from in front.



of it lies above the plane of the inlet of the pelvis. The internal urethral orifice sinks rapidly during the first three years of life, and then more slowly until the ninth year, after which it remains stationary until puberty, when it again slowly descends and reaches its adult position.

Ligaments.—Each side of the bladder is connected to the tendinous arch of the pelvic fascia (p. 603) by a condensation of fibro-areolar tissue which is often termed the *lateral true ligament* of the bladder. Anteriorly the same tissue forms two thickened bands, on each side of the median plane, termed the lateral and medial pubo-prostatic ligaments. The *lateral pubo-prostatic ligament* extends from the anterior end of the tendinous arch of the pelvic fascia downwards and medially to

*The Anatomy of the Child.

blend with the upper part of the sheath of the prostate; the *medial pubo-prostatic ligament* is attached to the back of the pubic bone near the middle of the symphysis and passes downwards and backwards to the sheath of the prostate, forming the floor of the retro-pubic space. In the female similar bands are termed *pubo-vesical ligaments*. The *apex* of the bladder is joined to the umbilicus by the remains of the urachus, which forms the *median umbilical ligament*. The lumen of the lower part of the urachus persists throughout life and is lined by modified, transitional epithelium. It may communicate with the cavity of the bladder.* As the veins of the vesical venous plexus stream backwards from the lateral borders of the base of the bladder to join the internal iliac veins, they are enveloped on each side in a band of fibro-areolar tissue which is sometimes termed the *posterior ligament* of the bladder.

From the superior surface of the bladder the peritoneum is carried off in a series of folds which are sometimes termed the *false ligaments* of the bladder. Anteriorly there are three folds: the *median umbilical fold* on the median umbilical ligament, and two *medial umbilical folds* on the obliterated umbilical arteries (fig. 1163). The reflections of the peritoneum from the bladder to the side walls of the pelvis form the lateral false ligaments while the sacrogenital folds (p. 1404) constitute the posterior false ligaments.

The interior of the bladder (fig. 1236).—The mucous membrane which lines the bladder is, over the greater part of the viscus, loosely attached to the muscular coat, and appears folded when the bladder is contracted: the folds are effaced when the bladder is distended. Over a small triangular area, named the *trigone of the bladder*, immediately above and behind the internal orifice of the urethra, the mucous membrane is firmly bound to the muscular coat, and is always smooth. The anterior angle of the trigone is formed by the internal orifice of the urethra: its posterolateral angles by the orifices of the ureters. The base of the trigone is formed by a slightly curved ridge, termed the *interureteric ridge*, which connects the two ureteral orifices and is produced by the continuation into the bladder-wall of the inner longitudinal coats of the ureters. The lateral parts of this ridge extend beyond the openings of the ureters; they are named the *ureteric folds* and are produced by the terminal portions of the ureters as they run obliquely through the bladder-wall. When the living bladder is examined with a cystoscope the interureteric ridge appears as a pale band, and forms an important guide during the operation of introducing a catheter into the ureter.

The *orifices of the ureters* are placed at the posterolateral angles of the trigone of the bladder, and are usually slit-like in form. In the contracted bladder they are about 2.5 cm. apart and about the same distance from the internal urethral orifice; in the distended bladder these measurements may be increased to about 5 cm.

The *internal urethral orifice* is placed at the apex of the trigone, in the most dependent part of the bladder, and is usually somewhat crescentic in form; in the adult male, particularly past middle age, the mucous membrane immediately behind it exhibits a slight elevation, caused by the median lobe of the prostate and termed the *uvula vesicae*.

Structure (fig. 1237).—The bladder is composed of three coats: serous, muscular and mucous.

The *serous coat* is a partial one, and is derived from the peritoneum. It invests the superior surface and the upper parts of the lateral surfaces in both sexes and, in the male the upper part of the posterior surface in addition.

The *muscular coat*, which constitutes the *detrusor muscle*, consists of three layers of unstriated muscular fibres: an external and an internal of longitudinal fibres, and a middle of circular fibres. As in the case of the ureter (p. 1482), there is much intermingling of the muscle fibres in these layers, so that they cannot be separated into three clearly defined strata.

The fibres of the *external longitudinal layer* pass in a more or less longitudinal manner, along the inferolateral surfaces of the bladder, over its apex on to the superior surface, and then descend over the base to become attached to the prostate and its capsule in the male, and to the front of the vagina in the female. Some of the longitudinal fibres are carried on to the front of the rectum, and are named the *Rectovesical muscle*. Others traverse the medial pubo-prostatic ligaments and are attached to the lower part of the pelvic surface of the pubis on each side. They are sometimes termed the *Pubovesical muscles*. At the sides of the bladder the fibres are arranged obliquely and intersect one another.

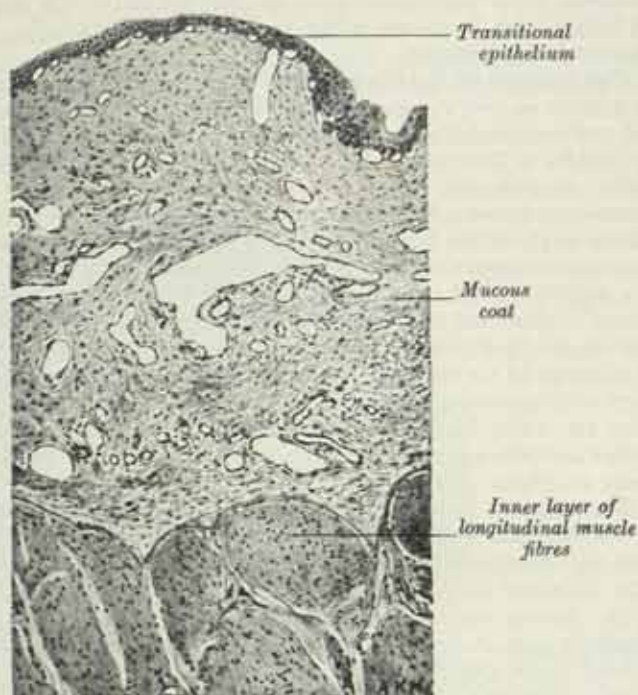
The fibres of the *middle circular layer* are very thinly and irregularly scattered on the body of the organ, and, although to some extent placed transverse to its long axis, are for the most part arranged obliquely. Towards the lower part of the bladder they are disposed in a circular layer, forming the *Sphincter vesicæ*, which surrounds the internal urethral orifice. Its fibres are continuous with prostatic muscle fibres which encircle the proximal part of the urethra.

The *internal longitudinal layer* is thin, and its fasciculi have a reticular arrangement, but with a tendency to assume for the most part a longitudinal direction.

Two bands of oblique fibres, originating behind the orifices of the ureters, converge to the back part of the prostate, and are inserted by means of a fibrous process into the median lobe of the organ. They are the *muscles of the ureters*, described by Bell, who supposed that during the contraction of the bladder they serve to retain the oblique direction of the ureters, and so prevent the reflux of the urine into them.

There is no muscularis mucosæ in the bladder wall.

FIG. 1237.—A vertical section through the wall of the bladder (human).



The *mucous coat* is thin, smooth, and of a pale rose colour. It is continuous above with that of the ureters, and below with that of the urethra; the epithelium covering it is of the transitional variety. The loose texture of the mucous layer allows the mucous coat to be thrown into folds or *rugæ* when the bladder is empty. Over the trigonum vesicæ the mucous membrane is closely attached to the muscular coat, and is not thrown into folds, but is smooth and flat. There are no true glands in the mucous membrane of the bladder, though certain mucous follicles which exist, especially near the neck of the bladder, have been regarded as such. The transitional epithelium of the ureter and bladder contains alkaline phosphatase, though the significance of this is not clear. Transplantation of pieces of bladder epithelium into the sheath of the Rectus abdominis muscle induces the formation of bone in that site,* but Johnson and McMinn† suggest that apart from alkaline phosphatase other factors may be involved in the induction of this heterotopic bone formation.

Vessels and Nerves.—The principal *arteries* of supply to the bladder are the superior and inferior vesical, derived from the anterior trunk of the internal iliac artery. The obturator and inferior gluteal arteries also send small branches to it, and in the female additional branches are derived from the uterine and vaginal arteries.

The *veins* form a complicated plexus on the inferolateral surfaces near the prostate,

* C. B. Huggins, *Arch. Surg., Chicago*, 1951, 22, 377.

† F. R. Johnson and R. M. H. McMinn, *J. Anat., Lond.*, 1956, 90, 106.

and pass backwards in the posterior ligaments of the bladder to end in the internal iliac veins.

The *lymph vessels* are described on p. 906.

The *nerves* of the bladder are (1) parasympathetic branches comprising fine medullated fibres from the second, third, and fourth sacral nerves, and forming synapses with ganglion-cells in the outer and mucous coats, and (2) sympathetic fibres. The preganglionic fibres are medullated and arise from the lower two thoracic and upper two lumbar segments of the spinal cord, and passing in the white rami communicantes they reach the sympathetic trunk which they traverse without interruption. They leave the trunk and pass to the superior hypogastric plexus and here form synapses in ganglia. The postganglionic fibres of both sympathetic and parasympathetics are non-medullated and are distributed to the muscular layer and epithelial lining of the viscus. The functions of the parasympathetic and sympathetic nerves supplying the bladder are described on p. 1221.

Applied Anatomy.—When the bladder is distended, it may be ruptured by violence applied to the abdominal wall, without any injury to the bony pelvis, or it may be torn in cases of fracture of the pelvis. The rupture may be either intraperitoneal or extraperitoneal; that is, may implicate the superior surface of the bladder in the former case, or one of the other surfaces in the latter.

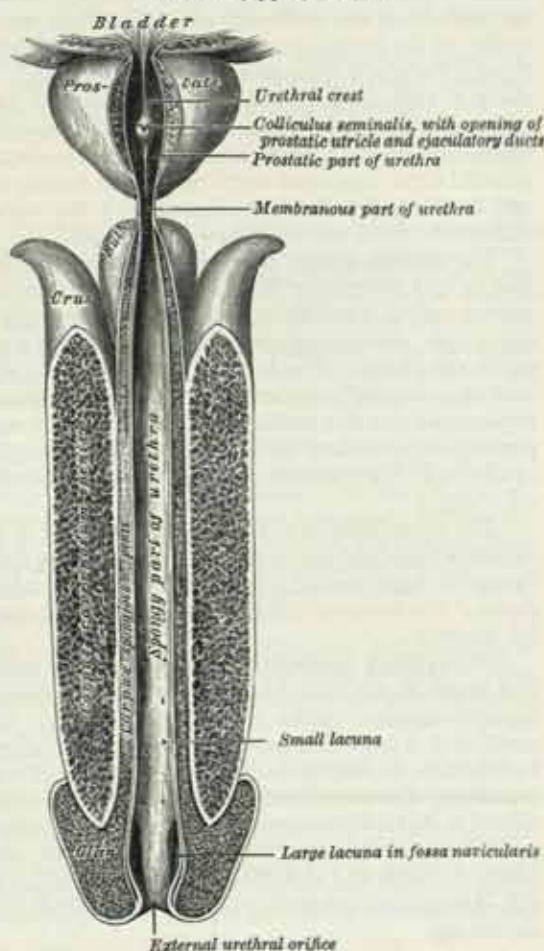
The muscular coat of the bladder undergoes hypertrophy in cases in which there is any obstruction to the flow of urine. In these circumstances the bundles of which the muscular coat consists become much increased in size, and, interlacing in all directions, give rise to what is known as the *trabeculated bladder*. Between these muscular bundles the mucous membrane may bulge out, forming sacculi, constituting *diverticula of the bladder*, and in these little pouches phosphatic concretions may collect, forming *encysted calculi*.

The interior of the bladder can be examined with the cystoscope. This instrument consists of a tube in which is fixed a small electric light, the wires of which run through the shaft of the instrument. When it is introduced along the urethra after distending the bladder with fluid the interior or the viscus can be examined with the eye. The orifices of the ureters can be examined, and renal hæmaturia diagnosed, and it can be definitely settled from which kidney the blood comes. A special cystoscope can be used to catheterise the ureter, for the purpose of obtaining a specimen of urine from either kidney, or to ascertain the condition of both kidneys when it is proposed to remove one. The outline of the bladder can be demonstrated by radiography after filling the viscus with sodium iodide solution introduced through a catheter.

Puncture of the distended bladder may be performed just above the symphysis pubis without wounding the peritoneum (suprapubic cystostomy). When the bladder contains about three-quarters of a pint of fluid, its anteroinferior surface is in contact with the anterior abdominal wall, without the intervention of peritoneum, for about three inches above the pubic crest.

Access to the bladder, for the purpose of removing calculi, is

FIG. 1238.—The male urethra laid open on its anterior (upper) surface.



almost always effected by the suprapubic route, the perineal operation being rarely used. In the female, owing to the shortness of the urethra and its ready dilatability, calculi and foreign bodies and new growths, when of small size, may be removed by the urethral route. Over-dilatation of the female urethra may cause incontinence of urine.

The congenital abnormalities of the bladder are described on p. 221.

THE MALE URETHRA (figs. 1232, 1238)

The **male urethra**, from 18 cm. to 20 cm. long, extends from the internal urethral orifice in the urinary bladder to the external urethral orifice at the end of the penis. It is divided into three portions, viz. *prostatic*, *membranous*, and *spongy*, and presents a double curve in the ordinary flaccid state of the penis (fig. 1232). Except during the passage of fluid along it, the urethral canal is a mere slit or cleft; in the prostatic portion the slit is transversely arched; in the membranous portion, irregular or stellate; in the spongy portion, transverse; while at the external orifice it is sagittal.

The **prostatic portion**, which is the widest and most dilatable part of the urethra, is about 3 cm. long, and runs almost vertically through the prostate from its base to its apex; it lies nearer the anterior than the posterior surface of the prostate. It is widest in the middle, and is narrowest below, where it joins the membranous portion: on transverse section it is crescentic with the convexity directed forwards.

Its shape on section is due to the presence on the posterior wall or floor of a narrow median longitudinal ridge formed by an elevation of the mucous membrane and its subjacent tissue termed the *urethral crest* (fig. 1243). On each side of the crest there is a shallow depression, termed the *prostatic sinus*, the floor of which is perforated by the *orifices of the prostatic ducts*. Near the middle of the urethral crest the *colliculus seminalis* forms an elevation on which the slit-like orifice of the prostatic utricle is situated; on each side of, or just within this orifice there is the small opening of the ejaculatory duct. The *prostatic utricle* is a cul-de-sac about 6 mm. long, which runs upwards and backwards in the substance of the prostate behind the median lobe. Its walls are composed of fibrous tissue, muscular fibres, and mucous membrane; the latter presents the openings of numerous small glands. It is developed from the united lower ends of the paramesonephric ducts, and is thought to be homologous with the vagina of the female (p. 211). The ejaculatory ducts are described on p. 1499.

The **membranous portion** is the shortest, least dilatable, and, with the exception of the external orifice, the narrowest part of the urethra. It runs a slightly curved course downwards and forwards from the prostate to the bulb of the penis (fig. 1232), perforating the perineal membrane about 2.5 cm. below and behind the pubic symphysis. The hinder part of the bulb of the penis lies in close apposition with the perineal membrane, but, in front of where the urethra enters, it is slightly separated from this fascia so that the anterior wall of the membranous urethra is prolonged for a short distance below the perineal membrane before it reaches the penile bulb; it measures about 2 cm. in length, while the posterior wall is only 1.25 cm. long.

The membranous portion of the urethra is surrounded by the fibres of the Sphincter urethræ (p. 609). In front of it the deep dorsal vein of the penis enters the pelvis between the transverse perineal ligament and the arcuate ligament of the pubis; the bulbo-urethral glands are placed one on each side of this portion of the urethra.

The **spongy portion** is contained in the corpus spongiosum penis (p. 1501). It is about 15 cm. long, and extends from the end of the membranous portion to the external urethral orifice on the glans penis. Commencing below the perineal membrane it passes forwards to the front of the lower part of the symphysis pubis; and then, in the flaccid condition of the penis, it bends downwards and forwards. It is narrow, with a uniform diameter of about 6 mm. in the body of the penis; it is dilated at its commencement to form the *intra-bulbar fossa*, and again within the glans penis, where it forms the *fossa navicularis*. The enlargement of the intra-bulbar fossa affects the floor and side-walls but not the roof of the urethra. The bulbo-urethral glands open into the spongy portion of the urethra about 2.5 cm. below the perineal membrane.

The *external urethral orifice* is the narrowest part of the urethra: it is a sagittal slit, about 6 mm. long, bounded on each side by a small labium.

The lining membrane of the urethra, except in the most anterior part of the tube, presents the orifices of numerous small mucous glands and follicles situated in the submucous tissue, and named the *urethral glands*. Besides these there are a number of small pit-like recesses, or *lacunæ*, of varying sizes; the orifices of these are directed forwards, and may intercept the point of a catheter in its passage along the canal. One lacuna, larger than the rest, is situated on the upper wall of the fossa navicularis; it is called the *lacuna magna*.

Sphincters.—Two sphincters surround the urethra, an internal and an external. The internal sphincter, or *Sphincter vesicæ* (p. 1488), controls the neck of the bladder and the prostatic urethra above the opening of the ejaculatory ducts. It is involuntary and is supplied by the sympathetic (the preganglionic fibres arising from the lower thoracic and upper lumbar nerves). The external sphincter, or *Sphincter urethræ* (p. 609), surrounds the membranous urethra and consists of striped muscle; it is supplied by the perineal branch of the pudendal nerve (S. 2, 3 and 4) and is under voluntary control after early infancy.

Structure.—The urethra is composed of mucous membrane, supported by a submucous tissue which connects it with the various structures through which it passes.

The *mucous membrane* of the urethra is continuous internally with that of the bladder, and externally with the skin covering the glans penis; it is prolonged into the ducts of the urethral, bulbo-urethral and prostatic glands, and into the deferent ducts and seminal vesicles, through the ejaculatory ducts. In the spongy and membranous portions of the urethra it is arranged in longitudinal folds when the tube is empty. Small papillæ are found upon it, near the external urethral orifice; its epithelial lining is of the transitional variety as far as the orifice of the ejaculatory duct; thereafter it is of the columnar variety, usually two or three layers deep, except near the external urethral orifice, where it is squamous and stratified.

The *submucous tissue* consists of a vascular erectile layer; outside this there is a layer of unstriped muscular fibres, arranged into an inner longitudinal and an outer circular layer and best marked in the prostatic and membranous portions.

Micturition.—Accumulation of urine in the bladder is accompanied by modification of tone of the detrusor muscle so that the intravesical tension does not rise greatly until a considerable filling of the bladder has occurred. When the tension in the bladder rises, sensory nerves are stimulated, the desire to micturate is felt and, if neglected, the sensation of fullness of the bladder and finally pain will supervene. These sensations are accompanied by rhythmic reflex contractions of the detrusor muscle. Until micturition is initiated, voluntary restraint is exercised by coincident inhibition of the detrusor and contraction of the *Sphincter urethræ* and the perineal muscles.* There is no evidence that the *Sphincter vesicæ* is under voluntary control but a reciprocal increase in tone of this muscle accompanies relaxation of the detrusor. The first stage of the act of micturition is a relaxation of the perineal muscles, except the *Sphincter urethræ*, and a contraction of the muscles of the abdominal wall. This is followed by firm contraction of the detrusor muscle and relaxation of the *Sphincter vesicæ*. The flow of urine begins on subsequent relaxation of the *Sphincter urethræ*, the bladder being emptied by the contraction of the detrusor assisted by the action of the muscles of the abdominal wall which raise the intra-abdominal pressure. As the act is completed, the bladder muscle relaxes and the *Sphincter vesicæ* contracts. Finally the *Sphincter urethræ* is closed and, in the male, the last drops of urine are expelled from the bulbar portion of the urethra by the action of the *Bulbocavernosus* muscle.

During ejaculation, the *Sphincter vesicæ*, as well as stopping the escape of urine, also prevents the regurgitation of the semen into the bladder.

Applied Anatomy.—The urethra may be ruptured, in which case extravasation of urine will occur if micturition be attempted. Extravasation most frequently takes place into the perineum superficial to the perineal membrane (inferior fascia of the urogenital diaphragm), but deep to the membranous layer of the superficial fascia. Both these layers of fascia are attached firmly to the ischiopubic rami. It is clear, therefore, that when extravasation of fluid takes place between them, it cannot pass backwards, because the two layers are continuous with each other around the Superficial transverse perineal muscles; it cannot extend laterally, on account of the connexion of these layers with the rami of the pubis and ischium; it cannot find its way into the pelvis, because the opening into this cavity is closed by the perineal membrane, and, therefore, so long as this layer remains intact, the only direction in which the fluid can make its way is forwards into the areolar tissue of the scrotum and the

* Denny-Brown, D., and Robertson, E. G., *Brain*, 56, 149, 1933.

penis, and thence on to the anterior wall of the abdomen. When the pelvis is crushed the urethra may be ruptured between the prostatic and membranous parts; the extravasation of urine then takes place into the extraperitoneal tissue of the pelvis.

THE FEMALE URETHRA (fig. 1235)

The **female urethra** is about 4 cm. long and 6 mm. in diameter. It begins at the internal urethral orifice of the bladder, opposite about the middle of the symphysis pubis, and runs downwards and forwards behind the symphysis pubis, *imbedded in the anterior wall of the vagina*. It perforates the perineal membrane and ends at the external urethral orifice, an anteroposterior slit with rather prominent margins, which is situated directly in front of the opening of the vagina and about 2.5 cm. behind the glans clitoridis. Except during the passage of urine the anterior and posterior walls of the urethra are in apposition, and the lining membrane is thrown into longitudinal folds, one of which, placed on the posterior wall of the canal, is termed the *urethral crest*. Many small *urethral glands* and minute pit-like recesses or *lacunæ* open into the urethra. Near the lower end of the urethra there are some small glands, which are considered to be the homologues of the prostatic gland of the male; on each side they are grouped together and open into a duct, named the *paraurethral duct*, which runs down in the submucous tissue, and ends in a small aperture on the lateral margin of the external urethral orifice. Developmentally, the female urethra corresponds to the part of the prostatic urethra in the male that lies proximal to the opening of the prostatic utricle.

Structure.—The female urethra has three coats: muscular, erectile and mucous.

The *muscular coat* is continuous with that of the bladder; it extends the whole length of the tube, and consists of inner longitudinal and outer circular fibres. At the upper end of the urethra, the circular muscle is thickened and forms the Sphincter vesicæ (internal sphincter). In addition to this, just above the perineal membrane, the female urethra is surrounded by the Sphincter urethræ, as in the male. The nerve-supply of these two sphincters is the same as that in the male (p. 1491).

A thin layer of *spongy erectile tissue*, containing a plexus of large veins, intermixed with bundles of unstriated muscular fibres, lies immediately beneath the mucous coat.

The *mucous coat* is pale; it is continuous externally with that of the vulva, and internally with that of the bladder. It is lined by stratified squamous epithelium, which becomes transitional near the bladder. Its external orifice is surrounded by a few mucous follicles.

THE MALE GENITAL ORGANS

The male genital organs include the *testes* and *epididymides*, the *deferent ducts*, the *seminal vesicles*, the *ejaculatory ducts* and the *penis*, together with the following accessory structures, viz. the *prostate* and the *bulbo-urethral glands*.

THE TESTES

The **testes**, the reproductive glands in the male, are suspended in the scrotum by the spermatic cords, the left testis hanging somewhat lower (about 1 cm.) than its fellow. The average dimensions of the testis are from 4 cm. to 5 cm. in length, 2.5 cm. in breadth, and 3 cm. in the anteroposterior diameter; its weight varies from 10.5 gm. to 14 gm. Each testis is of an ellipsoidal form (fig. 1239), compressed laterally, and has an oblique position in the scrotum; the upper extremity is tilted forwards and a little laterally; the lower, backwards and a little medially. The anterior border is convex, and looks forwards and downwards; the posterior border, nearly straight, looks backwards and upwards and to it the spermatic cord is attached.

The anterior border, the medial and lateral surfaces, and the extremities of the testis, are convex, free, smooth, and invested by the visceral layer of the tunica vaginalis (*vide infra*). The posterior border receives only a partial investment from that membrane. The epididymis lies along the lateral part of the posterior border.

The **epididymis** consists essentially of a tortuous canal which forms the first part of the efferent duct of the testis. This canal is folded on itself and tightly packed into the form of a long, narrow, flattened body attached to the lateral part of the posterior border of the testis. It consists of a central portion, or *body*; an upper enlarged end, or *head*; and a lower pointed end, or *tail*. The head is intimately

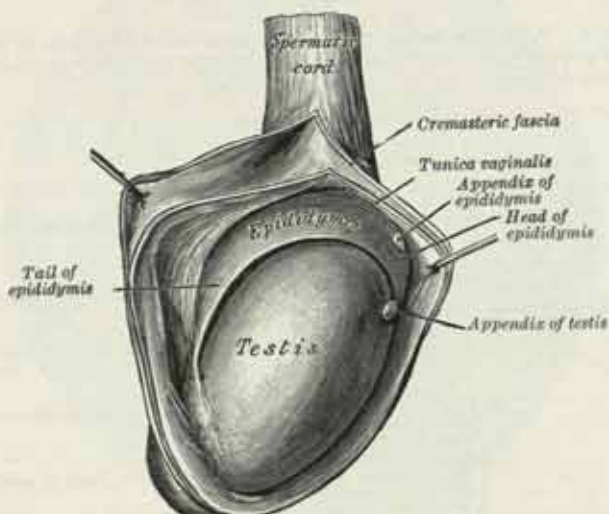
connected with the upper end of the testis by means of the efferent ductules of the gland; the tail is connected with the lower end by areolar tissue and a reflection of the tunica vaginalis. The lateral surfaces of the head and tail of the epididymis are free and covered by the tunica vaginalis; the body is also invested by it, except at its posterior border. A recess of the tunica vaginalis, named the *sinus of the epididymis*, lies between the body of the epididymis and the lateral surface of the testis.

The appendages of the testis and epididymis.—On the upper extremity of the testis, just beneath the head of the epididymis, there is a minute, oval, sessile body, termed the *appendix of the testis*; it is the remnant of the upper end of the paramesonephric duct. On the head of the epididymis there is a small, stalked appendage (sometimes duplicated); it is named the *appendix of the epididymis*, and is usually considered to be a derivative of the mesonephros.

The testis is invested by three tunics: the tunica vaginalis, tunica albuginea and tunica vasculosa.

The **tunica vaginalis** (figs. 1239, 1244) is the lower portion of the processus vaginalis of the peritoneum, which, in the fœtus, preceded the descent of the testis

FIG. 1239.—The right testis. Exposed by laying open the lateral part of the tunica vaginalis.



from the abdomen into the scrotum (p. 214). After the testis has reached the scrotum the upper part of the processus vaginalis, viz. from the deep inguinal ring to within a short distance of the testis, contracts and undergoes obliteration. The lower portion remains as a closed sac, which invests the surface of the testis, and is reflected on to the internal surface of the scrotum; hence it may be described as consisting of a visceral and a parietal layer.

The *visceral layer* covers the lateral and medial surfaces and the anterior border of the testis, but leaves most of the posterior border uncovered. At the medial side of the posterior border it is reflected forwards to become continuous with the parietal layer. At the lateral side of the posterior border it is reflected on to the medial aspect of the epididymis, lining the sinus of the epididymis, and then over its lateral aspect as far as its posterior border, where it is reflected forwards to become continuous with the parietal layer. The continuity between the visceral and parietal layers is established also at the upper and lower poles of the testis, but at the upper pole the visceral layer covers the upper surface of the head of the epididymis before being reflected.

The *parietal layer* is more extensive than the visceral; it reaches below the testis and extends upwards for some distance in front and on the medial side of the spermatic cord. The inner surface of the tunica vaginalis is smooth, and covered with a layer of mesothelial cells. The potential space between the visceral and parietal layers constitutes the cavity of the tunica vaginalis.

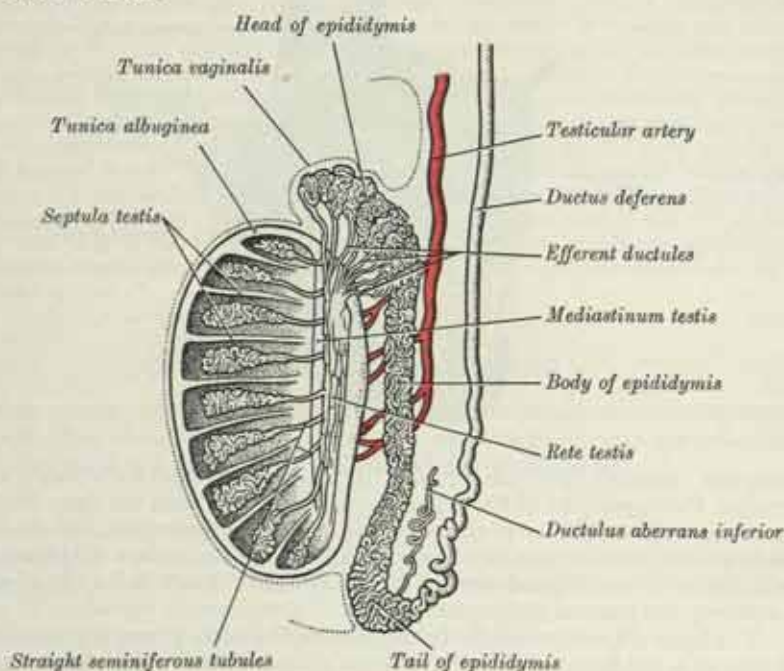
In the embryo, the gonad (testis or ovary) projects into the cœlomic cavity and is covered by germinal epithelium; some consider that even in the adult the testis

(like the ovary) is not covered by true peritoneum, the layer of mesothelium on the surface of the organ being the remnant of the original germinal epithelium. The tunica vaginalis would thus be considered to consist of a parietal layer only and to become continuous with the germinal epithelium at the posterior border of the testis.

The obliterated portion of the processus vaginalis may frequently be seen as a fibrous thread in the anterior part of the spermatic cord; sometimes this thread may be traced from the upper end of the inguinal canal, where it is connected with the peritoneum, down to the tunica vaginalis; sometimes it is lost in the spermatic cord. In some instances the upper part of the processus vaginalis is not obliterated, and the peritoneal cavity then communicates with the tunica vaginalis; in others the upper part of the processus vaginalis may persist but its lower end is shut off from the tunica vaginalis (p. 1496).

The **tunica albuginea** forms a fibrous covering for the testis. It is a dense membrane, of a bluish-white colour, composed of interlacing bundles of white fibrous tissue. It is covered with the visceral layer of the tunica vaginalis, except at the head and tail of the epididymis, and along the posterior border of the testis, where the testicular vessels and nerves enter the gland. It is applied to the tunica vasculosa, and, at the posterior border of the testis, is projected into the interior of

FIG. 1240.—A vertical section through the testis and epididymis, to show the arrangement of the ducts of the testis and the mode of formation of the ductus deferens.



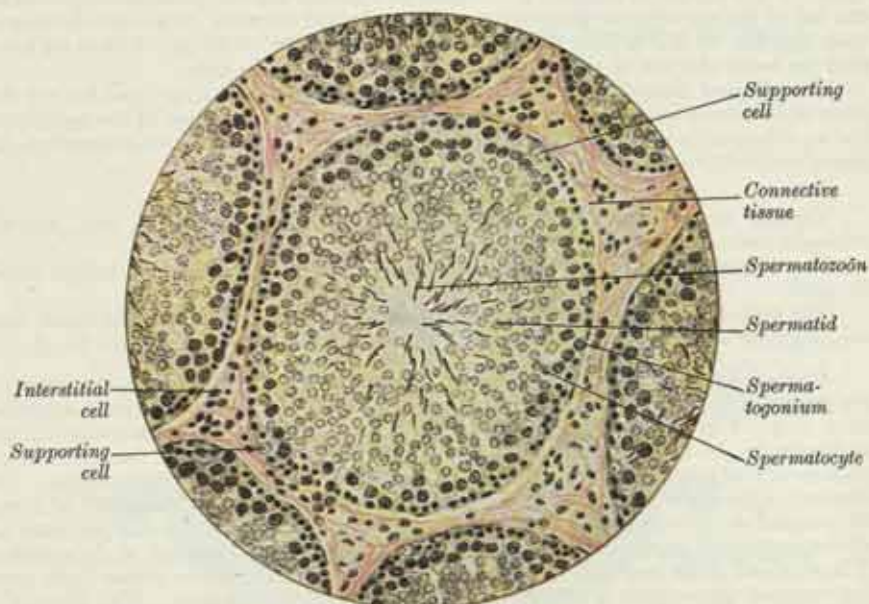
the gland, forming an incomplete, vertical septum, called the *mediastinum testis* (fig. 1244). This extends from the upper to near the lower end of the gland, and is wider above than below. From its front and sides numerous imperfect septa [*septula testis*] are given off and radiate towards the surface of the testis, where they are attached to the deep aspect of the tunica albuginea. They divide the testis incompletely into a number of cone-shaped lobules.

The bases of the lobules are at the surface of the testis, and their apices converge to the mediastinum. The mediastinum contains the vessels and ducts of the testis in their passage to and from the substance of the gland.

The **tunica vasculosa** is the vascular layer of the testis, consisting of a plexus of blood-vessels held together by delicate areolar tissue. It lines the tunica albuginea and clothes the septa, and therefore forms an investment to all the lobules of the testis.

Structure.—The covering of the testis consists of a layer of flattened mesothelial cells similar to those which line the peritoneal cavity; by some these mesothelial cells are considered to be remnants of the germinal epithelium. The glandular structure of the testis consists of the lobules of the testis (fig. 1240). Their number, in a single testis, is estimated to be between 200 and 300. They differ in size according to their position, those in the middle of the testis being larger and longer. Each lobule contains from one to three, or more, minute convoluted tubes, termed the convoluted seminiferous tubules [*tubuli seminiferi contorti*]. When the tubules have been unravelled by careful dissection under water, they are seen to commence either by free blind ends or by anastomotic loops. They are supported by loose connective tissue which contains here and there groups of *interstitial cells* (fig. 1241) containing yellow pigment granules. The total number of tubules in each testis is estimated to be between 400 and 600, and the average length of each is 70 cm. to 80 cm. Their diameter varies from 0.12 mm. to 0.3 mm. The tubules are pale in colour in early

FIG. 1241.—A transverse section through a part of a human testis. Stained with iron hæmatoxylin and Van Gieson's stain. $\times 6350$.



life, but in old age they contain much fatty matter and acquire a deep yellow tinge. Each tubule (fig. 1241) consists of a basement-layer formed of laminated connective tissue containing numerous elastic fibres, with flattened cells between the layers, and covered externally with a layer of flattened epithelioid cells. Within the basement-membrane epithelial cells are arranged in three irregular layers. 1. An outer layer of cubical cells, with small nuclei; some of these enlarge to become *spermatogonia*. The nuclei of some of the spermatogonia may be seen to be in process of division (see p. 60), and in consequence of this, daughter cells are formed which constitute the second zone. 2. Larger polyhedral cells, with clear nuclei, arranged in two or three layers; these are the *intermediate cells* or *spermatocytes*. The cells of the first row are the *primary spermatocytes*, formed by homotypical division of the spermatogonia. Their nuclei therefore contain chromatin material corresponding to the diploid somatic number of chromosomes and are much more darkly stained than the nuclei of the cells of the next row, the *secondary spermatocytes*. The latter, being formed by meiotic division of primary spermatocytes, contain only half the amount of chromatin material in their nuclei which take up much less stain (fig. 1241) (haploid number of chromosomes). 3. The next layer of cells consists of the *spermatids*, each of which becomes a *spermatozoön*. The spermatids are small polyhedral cells, the nucleus of each containing the haploid number of chromosomes. The changes which occur during the conversion of the spermatids into spermatozoa are described and illustrated on p. 62. In addition to these three layers of cells, others, termed the *supporting cells*, or *cells of Sertoli*, are seen. They are elongated and columnar, and project inwards from the basement-membrane towards the lumen of the tube. As development of the spermatozoa proceeds, the latter become partially imbedded in the

cytoplasm of the supporting cells. Ultimately the spermatozoa are liberated and set free. The structure of the spermatozoa is described on p. 60.

In the apices of the lobules, the tubules become less convoluted, assume a nearly straight course, and unite at acute angles to form from twenty to thirty larger straight ducts, of about 0.5 mm. in diameter, called straight tubules (fig. 1240).

The straight seminiferous tubules [*tubuli seminiferi recti*] enter the fibrous tissue of the mediastinum, and pass upwards and backwards, forming, in their ascent, a close network of anastomosing tubes lined by flattened epithelium; this network is named the *rete testis*. At the upper end of the mediastinum these tubes terminate in from twelve to twenty ducts, termed the *efferent ductules*; they perforate the tunica albuginea, and pass from the testis to the epididymis. Their course is at first straight; then they become enlarged and exceedingly convoluted, and form a series of conical masses, known as the *lobules of the epididymis*, which together constitute the head of the epididymis. Each lobule consists of a single convoluted duct, from 15 cm. to 20 cm. in length. Opposite the bases of the lobules the ducts open into a single canal, the *duct of the epididymis*, which constitutes, by its complex convolutions, the body and tail of the epididymis. When the convolutions are unravelled, this tube measures upwards of 6 metres in length; it increases in diameter and thickness as it approaches the tail of the epididymis where it becomes the ductus deferens. The convolutions are held together by fine areolar tissue, and by bands of fibrous tissue. It is to be noted that the body and tail of the epididymis consist of one tube only.

The efferent ductules are lined by ciliated columnar epithelium and have a thin layer of circularly arranged muscle fibres in their walls. In the duct of the epididymis the muscle coat becomes thicker and the epithelium is columnar pseudostratified, the superficial cells having long, non-motile stereocilia.

Vessels and Nerves.—The *testicular artery* is described on p. 805, and the *testicular veins* on p. 872.

The *lymph vessels* of the testis end in the lateral and pre-aortic lymph nodes (p. 906).

The *nerves* accompany the testicular vessels, and are derived from the tenth thoracic segment of the spinal cord, through the renal and aortic plexuses (p. 1217).

Applied Anatomy.—At an early period of intrauterine life the testes are placed in the posterior part of the abdominal cavity. Their descent into the scrotum is described on p. 214. The descent appears to be under hormonal control (gonadotrophins and androgens). In the scrotum the testes lie in a colder environment than that in the abdomen, and it is believed that the lower temperature favours spermatogenesis. The descent of the testis may be arrested. It may be retained in the abdomen; or it may be arrested at the deep inguinal ring, or in the inguinal canal; or it may just pass out of the superficial inguinal ring without finding its way to the bottom of the scrotum. The retained testis is probably useless sexually; so that a man in whom both testes are retained (*anorchism*) is sterile, though he may not be impotent. The absence of one testis is termed *monorchism*. When a testis is retained in the inguinal canal it is often complicated with a congenital hernia, the processus vaginalis of the peritoneum not being obliterated. The testis may descend through the inguinal canal, but may miss the scrotum and assume some abnormal position (ectopia testis) (p. 215).

The testis may be inverted within the scrotum so that its posterior or attached border is directed forwards and the tunica vaginalis is situated behind. Should a hydrocele occur, and tapping be resorted to, the trocar may be thrust into the testis, unless care be taken beforehand to ascertain the position of the gland.

Torsion of the spermatic cord, resulting in acute strangulation of the testis sometimes occurs. In consequence of the torsion the circulation is partly arrested and the organ swells and becomes acutely painful.

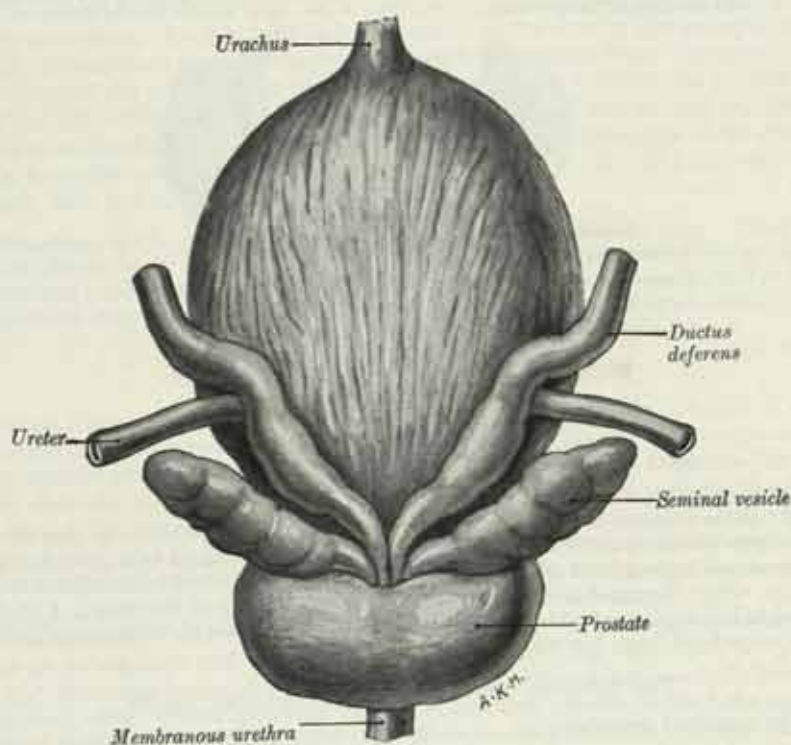
Fluid collections of a serous character are frequently found in the scrotum. To these the term *hydrocele* is applied. The most common form is the ordinary *vaginal hydrocele*, in which the fluid is contained in the sac of the tunica vaginalis. In another form, the congenital hydrocele, the fluid is in the sac of the tunica vaginalis, but this sac communicates with the general peritoneal cavity, owing to the non-obliteration of the upper part of the processus vaginalis. A third variety, known as an *infantile hydrocele*, occurs in those cases where the processus vaginalis is obliterated only at or near the deep inguinal ring. It resembles the vaginal hydrocele, except as regards its shape, the collection of fluid extending up the cord into the inguinal canal. Fourthly, the processus vaginalis may be obliterated both at the deep inguinal ring and above the epididymis, leaving a central unobliterated portion, which may become distended with fluid, giving rise to a condition known as *encysted hydrocele of the cord*.

Encysted hydrocele of the epididymis, or *spermatocele*, is the name given to a cyst found in connexion with the head of the epididymis. Among its contents are found a varying number of spermatozoa, and it is probably a retention cyst of one of the tubules.

THE DUCTUS DEFERENS

The **ductus deferens** is the continuation of the duct of the epididymis (fig. 1240). Commencing at the lower part of the tail of the epididymis, it is at first very tortuous, but gradually becoming straighter it ascends along the posterior border of the testis and the medial side of the epididymis. From the upper pole of the testis it runs upwards in the posterior part of the spermatic cord, and traverses the inguinal canal to the deep inguinal ring. Here it separates from the other structures of the spermatic cord, curves round the lateral side of the inferior epigastric artery, and ascends for about 2.5 cm. in front of the external iliac artery. It is next directed backwards and slightly downwards, and, crossing the external iliac vessels obliquely, enters the pelvic cavity, where it is continued backwards between the peritoneum and the lateral wall of the pelvis, and on the medial side of the obliterated umbilical artery, the obturator nerve and vessels, and the vesical vessels (fig. 1232). It then crosses the ureter (fig. 1242), and, reaching the medial side of this tube, bends at an acute

FIG. 1242.—The bladder, seminal vesicles, etc. Viewed from above and behind.



angle, and runs medially and slightly forwards between the base of the bladder and the upper end of the seminal vesicle. Reaching the medial side of the seminal vesicle, it is directed downwards and medially in contact with it, and gradually approaches the opposite duct. Here it lies between the base of the bladder and the rectum, from which it is separated by the recto-vesical fascia. Lastly, it passes downwards to the base of the prostate, and is joined at an acute angle by the duct of the seminal vesicle to form the ejaculatory duct (fig. 1243). Owing to the thickness of its wall relative to the small size of its lumen, the ductus deferens feels hard and cord-like when grasped by the finger and thumb. Its canal in the greater part of its extent is of extremely small calibre, but at the base of the bladder it becomes dilated and tortuous, and this portion is termed the *ampulla*; its terminal portion, which joins the duct of the seminal vesicle, is again greatly diminished in calibre (fig. 1243).

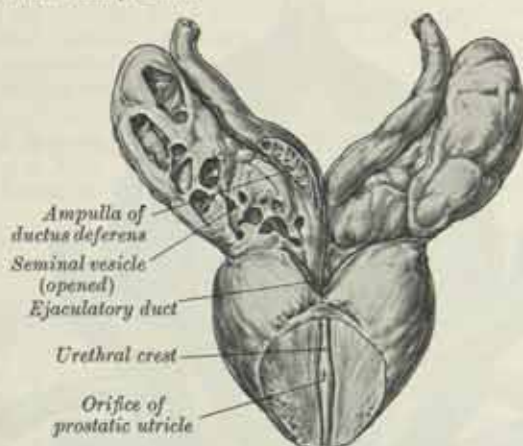
Ductuli aberrantes.—A long narrow tube, termed the *ductulus aberrans inferior*, is frequently found connected with the lower part of the duct of the epididymis, or with

the commencement of the ductus deferens. Its length, when it is uncoiled, varies from 5 cm. to 35 cm., and it may be dilated towards its blind extremity, or may be of uniform diameter throughout. Its structure is similar to that of the ductus deferens. Occasionally it is found unconnected with the epididymis. A second tube, termed the *ductulus aberrans superior*, occurs in the head of the epididymis, and is connected with the rete testis. These aberrant ductules are derived from mesonephric tubules (p. 207).

Paradidymis.—This term is applied to a small collection of convoluted tubules, situated in front of the lower part of the spermatic cord above the head of the epididymis. These tubes are lined with ciliated columnar epithelium, and probably represent the remains of a part of the mesonephros (p. 207).

Structure.—The ductus deferens consists of three coats : (1) an external or areolar coat ; (2) a thick muscular coat, which in the greater part of the tube consists of two layers of unstriated muscular fibres : an outer, longitudinal in direction, and an inner, circular ; but at the commencement of the duct there is a third layer, consisting of longitudinal fibres, and placed between the circular stratum and the mucous mem-

FIG. 1243.—The seminal vesicles, the terminal portions of the deferent ducts, and the prostate, exposed from in front. The anterior walls of the right seminal vesicle and of the ampulla of the right ductus deferens have been removed, and the prostatic part of the urethra has been opened from in front by the removal of a portion of the prostate.



brane ; there is much intermingling of the fibres in the above layers so that they do not constitute clearly defined strata ; (3) an internal, or mucous coat, which is pale, and arranged in longitudinal folds. The mucous coat is lined with columnar epithelium, which is non-ciliated throughout the greater part of the tube ; a variable portion of the testicular end of the tube is lined with two strata of columnar cells, those of the superficial layer having non-motile stereocilia.

THE SEMINAL VESICLES AND EJACULATORY DUCTS

The **seminal vesicles** (fig. 1242) are two sacculated pouches, placed between the base of the bladder and the rectum. Each vesicle is about 5 cm. long, and is somewhat pyramidal in form, the broad end being directed backwards, upwards and laterally. It consists of a tube, coiled upon itself, and giving off several irregular diverticula (fig. 1243) ; the separate coils, as well as the diverticula, are connected together by fibrous tissue. The tube has a diameter of 3-4 mm. and its length when uncoiled varies from 10 cm. to 15 cm. ; it ends above in a cul-de-sac ; its lower extremity becomes constricted into a narrow straight duct, which joins with the corresponding ductus deferens to form the ejaculatory duct. The *anterior surface* is in contact with the base of the bladder, extending from near the termination of the ureter to the base of the prostate. The *posterior surface* rests upon the rectum, from which it is separated by the recto-vesical fascia. The vesicles diverge from each other above, and are in relation with the deferent ducts and the terminations of the ureters, and are partly covered with peritoneum ; each is enveloped in a dense, fibro-muscular sheath. Along the medial margin of the vesicle runs the ampulla of the ductus deferens. Lateral to the vesicle, the veins of the prostatic venous plexus pass backwards to join the internal iliac vein.

Structure.—The seminal vesicles are composed of three coats: an *external* or *areolar coat*; a *middle* or *muscular coat*, thinner than that of the ductus deferens and arranged in two layers, an outer longitudinal and an inner circular; an *internal* or *mucous coat*, which is pale, of a whitish-brown colour, and presents a delicate, reticular structure. The epithelium is columnar, and in the diverticula goblet-cells are present, the secretion of which forms a large part of the seminal fluid. The secretion is slightly alkaline, and contains fructose and a coagulating enzyme (vesiculase). The seminal vesicles do not form a storage place for sperms. The latter, passing from the testis, are stored in the epididymis (and possibly in the ampulla of the ductus deferens).

Vessels and Nerves.—The *arteries* supplying the seminal vesicles are derived from the inferior vesical, and the middle rectal arteries. The *veins* and *lymph vessels* accompany the arteries. The *nerves* are derived from the pelvic plexuses.

Applied Anatomy.—The seminal vesicles are often the seat of the disease in cases of tuberculosis of the genito-urinary tract, and should always be examined from the rectum, in cases where the testes are involved. They also become affected in chronic posterior urethritis of gonorrhœal origin. An abscess of the seminal vesicle may rupture into the peritoneal cavity and cause fatal peritonitis.

The **ejaculatory ducts** (figs. 1232, 1243) are two in number, one on each side of the median plane. Each is formed by the union of the duct of the seminal vesicle with the terminal part of the ductus deferens, and is nearly 2 cm. long. They commence at the base of the prostate, run forwards and downwards between the median and right (or left) lobes, pass along the sides of the prostatic utricle, and end on the colliculus seminalis in slit-like orifices on, or just within, the margins of the opening of the prostatic utricle (p. 1490). The ducts diminish in size, and also converge, towards their terminations.

Structure.—The coats of the ejaculatory ducts are extremely thin. They are: an *outer fibrous layer*, which is almost entirely lost after the entrance of the ducts into the prostate; a *layer of muscular fibres*, consisting of a thin outer circular, and an inner longitudinal layer; and *mucous membrane* covered with columnar epithelium.

THE SPERMATIC CORD AND ITS COVERINGS

When the testis descends through the abdominal wall into the scrotum, it drags its vessels and nerves and the ductus deferens with it. These structures meet at the deep inguinal ring and together form the *spermatic cord*, which suspends the testis in the scrotum, and extends from the deep inguinal ring to the posterior border of the testis; the left spermatic cord is a little longer than the right. Between the superficial inguinal ring and the testis the cord lies anterior to the tendon of origin of the Adductor longus where it is crossed superficially by the superficial external pudendal artery and deeply by the deep external pudendal artery.

The spermatic cord traverses the inguinal canal (p. 601) having the walls of the canal as its relations and with the ilioinguinal nerve lying below it. In passing through the canal it acquires coverings from the different layers which form the abdominal wall. These coverings extend downwards into the wall of the scrotum and are named, from within outwards, the internal spermatic, cremasteric and external spermatic fasciæ.

The *internal spermatic fascia* is a thin layer which loosely invests the spermatic cord, and is derived from the transversalis fascia (p. 601).

The *cremasteric fascia* consists of a number of muscular fasciculi, united to one another by areolar tissue; the muscular fasciculi constitute the Cremaster and are continuous with the Obliquus internus abdominis (p. 594).

The *external spermatic fascia* is a thin fibrous membrane continuous above with the aponeurosis of the Obliquus externus abdominis, and prolonged downwards from the crura of the superficial ring (p. 591).

Structure of the spermatic cord.—The spermatic cord is composed of arteries, veins, lymph vessels, nerves, and the ductus deferens, connected together by areolar tissue.

The *arteries* of the spermatic cord are: the testicular artery (p. 872), the artery to the cremaster (p. 817) and the artery of the ductus deferens (p. 809).

The *testicular veins* are described on p. 892.

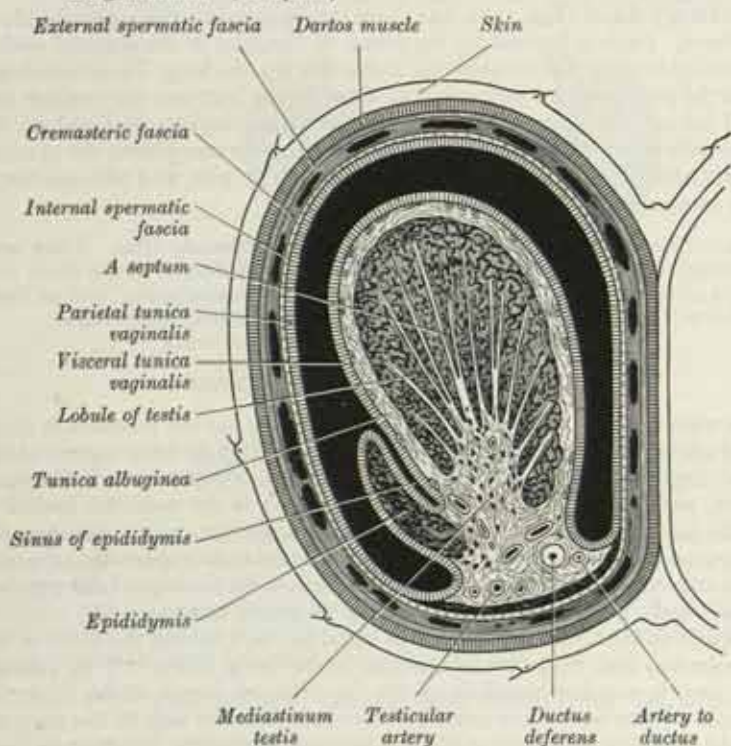
The *lymph vessels* of the testis are described on p. 906.

The *nerves* are (1) the genital branch of the genitofemoral nerve (p. 1174), and (2) the testicular plexus of the sympathetic (p. 1217), joined by filaments from the pelvic plexus which accompany the artery of the ductus deferens.

THE SCROTUM

The *scrotum* is a cutaneous pouch containing the testes and the lower parts of the spermatic cords, and placed below the pubic symphysis in front of the upper parts of the thighs. It is divided on its surface into a right and a left portion by a ridge, or *raphe*, which is continued forwards to the under surface of the penis, and backwards along the middle line of the perineum to the anus; the left portion hangs lower than the right, in correspondence with the greater length of the left spermatic cord. The raphe indicates the bilateral origin of the scrotum from the genital swellings (p. 218). The external appearance varies in different circumstances: thus, under

FIG. 1244.—A transverse section through the left half of the scrotum and the left testis. The sac of the tunica vaginalis is represented in a distended condition. Diagrammatic. (Delépine.)



the influence of warmth, and in old and debilitated persons, the scrotum is elongated and flaccid; but, under the influence of cold, and in the young and robust, it is short, corrugated, and closely applied to the testes. It consists of the skin and the dartos muscle, together with the external spermatic, cremasteric and internal spermatic fasciæ, already described in connexion with the spermatic cord. The inner surface of the internal spermatic fascia is in contact with the parietal layer of the tunica vaginalis (fig. 1244).

The *skin* is very thin, of a brownish colour, and generally thrown into folds or rugæ. It is beset with thinly scattered, crisp hairs, the roots of which are visible through the skin; it is provided with sebaceous follicles, the secretion of which has a peculiar odour.

The *dartos muscle* is a thin layer of non-striped muscular fibres, continuous around the base of the scrotum, with the superficial fascia of the groin and of the perineum. It sends inwards a septum (the *septum of the scrotum*), which connects the raphe to the under surface of the root of the penis, and divides the scrotal

pouch into two cavities for the testes. The scrotal septum is composed of all the layers of the scrotal wall, except the skin which forms one continuous investment to the entire scrotum. The dartos muscle is closely united to the skin, but is connected with the subjacent parts by delicate areolar tissue, upon which it glides with the greatest facility. The subcutaneous tissue of the scrotum is entirely devoid of fat.

Vessels and Nerves.—The *arteries* supplying the scrotum are: the external pudendal branches of the femoral artery (p. 821), the scrotal branches of the internal pudendal artery (p. 812), and the cremasteric branch from the inferior epigastric artery (p. 817). The *veins* follow the course of the corresponding arteries. The *lymph vessels* end in the inguinal lymph nodes (p. 896). The *nerves* are the ilio-inguinal and genital branch of the genitofemoral (p. 1174), the two scrotal branches of the perineal nerve (p. 1190), and the perineal branch of the posterior femoral cutaneous nerve (p. 1182). It is to be noted that the anterior third of the scrotum is supplied mainly from the first lumbar segment of the spinal cord (through the ilio-inguinal and genitofemoral nerves), whereas the posterior two-thirds are supplied mainly from the third sacral segment (through the perineal and posterior femoral cutaneous nerves).

Applied Anatomy.—The scrotum forms a covering for the protection of the testes. These bodies, lying suspended and loose in the cavity of the scrotum and surrounded by serous membrane, are capable of great mobility, and can therefore easily slip about within the scrotum, and thus avoid injuries from blows or squeezes. The skin of the scrotum is very elastic and capable of great distension, and on account of the looseness and amount of subcutaneous tissue, the scrotum becomes greatly enlarged in cases of oedema, to which this part is especially liable as a result of its dependent position.

THE PENIS

The **penis** is the male organ of copulation. It comprises an attached portion, termed the *root*, which is situated in the perineum, and a free, pendulous portion, termed the *body*, which is completely enveloped in skin.

The **root of the penis** comprises three masses of erectile tissue which lie in the urogenital triangle of the perineum. They include the two crura and the bulb of the penis, which are firmly attached to the margins of the pubic arch and the perineal membrane, respectively.

The *crus penis* (fig. 1245) commences behind in a blunt-pointed process, which is attached to the bone immediately in front of the ischial tuberosity. It is an elongated structure, closely applied and firmly adherent to the everted border of the conjoined pubic and ischial rami, and covered with the Ischiocavernosus muscle (p. 608). Anteriorly it converges on its fellow of the opposite side, presenting a slight enlargement just behind this point. Near the lower border of the pubic symphysis the two crura bend sharply downwards and forwards to become continuous with the corpora cavernosa of the body of the penis.

The *bulb of the penis* (fig. 1245) occupies the interval between the two crura and is firmly connected to the lower surface of the perineal membrane, from which it receives a fibrous investment. Oval in outline, it narrows anteriorly to become continuous with the corpus spongiosum of the body of the penis, bending sharply downwards and forwards as it does so. Its convex superficial surface is completely covered with the Bulbocavernosus muscle; its flattened deep surface is pierced above its centre, by the urethra, which traverses its substance to gain the corpus spongiosum. It is this part of the urethra which exhibits the intra-bulbar fossa (p. 1490).

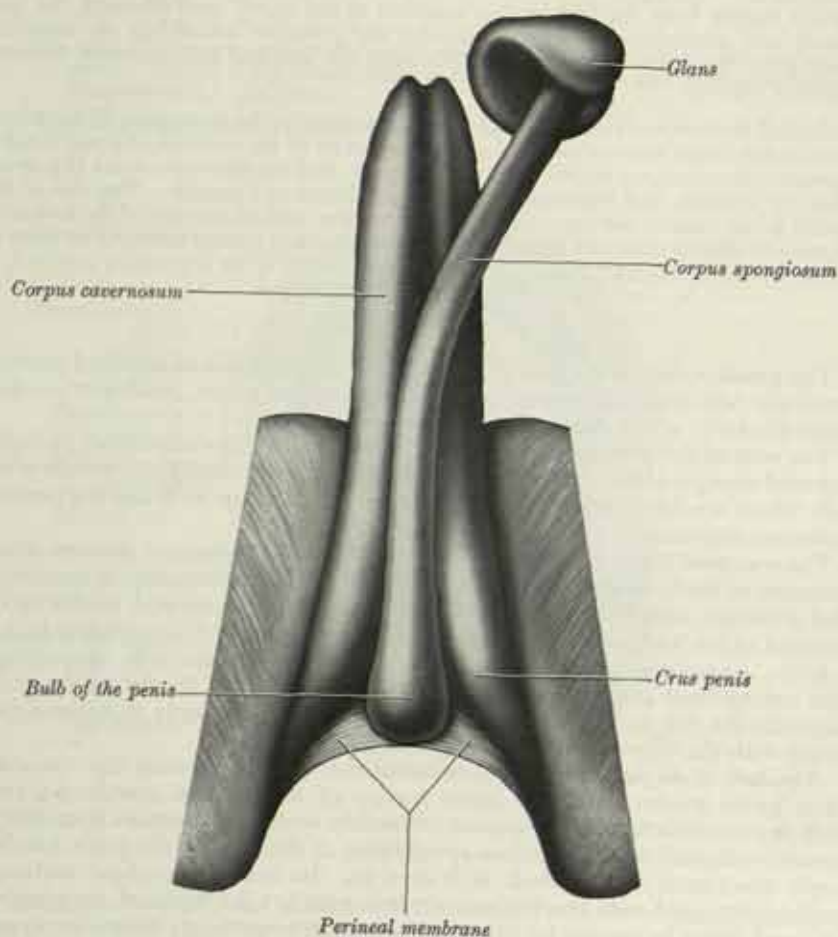
The **body of the penis** is composed of three elongated masses of erectile tissue which are capable of considerable enlargement when they are engorged with blood during erection of the organ. When flaccid, the body of the penis is cylindrical in shape, but when erect, it assumes the form of a triangular prism with rounded angles. The surface which faces upwards and backwards during erection is spoken of as the '*dorsum*' of the penis, and the opposite surface as the '*venter*' or *urethral surface*. The masses of erectile tissue are termed the right and left corpora cavernosa and the corpus spongiosum penis.

The *corpora cavernosa penis* form the greater part of the substance of the body of the penis. Throughout their whole length they are in close apposition with each other, being surrounded by a common fibrous envelope and being separated by a

median fibrous septum. On the urethral surface the combined mass shows a wide median groove, which lodges the corpus spongiosum (fig. 1246), and on the dorsal surface, a similar but narrower groove lodges the deep dorsal vein of the penis. The two corpora cavernosa do not reach the end of the organ but terminate, under cover of the glans penis, in a blunted conical extremity, on which each forms a small projection (fig. 1245). Proximally, each becomes continuous with the corresponding crus penis.

The corpora cavernosa penis are surrounded by a strong, fibrous envelope (tunica albuginea) consisting of superficial and deep fibres. The superficial fibres

FIG. 1245.—The constituent cavernous cylinders of the penis. The glans penis and the anterior part of the corpus spongiosum penis are detached from the corpora cavernosa penis and turned to one side.



are longitudinal in direction, and form a single tube which encloses both corpora; the deep fibres are arranged circularly round each corpus, and form by their junction in the median plane the *septum of the penis*. This septum is thick and complete behind, but is imperfect in front, where it consists of a series of bands arranged like the teeth of a comb; it is therefore sometimes named the *septum pectiniforme*.

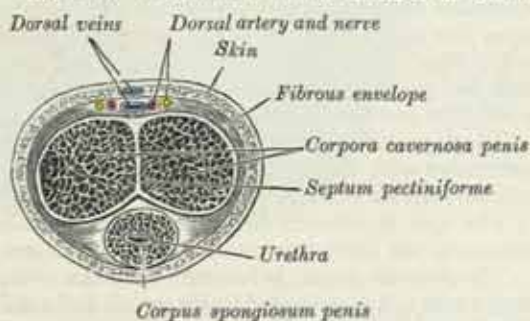
The *corpus spongiosum penis*, which is traversed throughout its whole length by the spongy part of the urethra, lies in the median groove on the urethral surface of the conjoined corpora cavernosa. It is cylindrical in form and tapers slightly from behind forwards. It is surrounded by a fibrous sheath (tunica albuginea). Near the extremity of the penis it suddenly expands to form a conical enlargement, termed the glans penis (fig. 1245), and, traced towards the perineum, it becomes directly continuous with the bulb.

The *glans penis* projects dorsally so as to cover the free extremities of the corpora cavernosa to which it presents a shallow concave surface for their attachment. The base of the glans has a projecting margin, termed the *corona glandis*, which overhangs an obliquely grooved constriction, sometimes referred to as the *neck of the penis*. The fossa navicularis (p. 1490) of the urethra lies within the glans and opens by a sagittal slit on or near its apex.

The skin covering the penis is remarkable for its thinness, its dark colour and its looseness of connexion with the fascial sheath of the organ. At the neck of the penis it is folded upon itself to form the *prepuce* or *foreskin*, which overlaps the glans for a variable distance. The internal layer of the prepuce is confluent along the line of the neck with the thin skin which covers, and adheres firmly to, the glans, and is continuous with the mucous membrane of the urethra at the external urethral orifice. On the under surface of the glans penis a small median fold passes from the deep surface of the prepuce to a point on the glans immediately behind the external urethral orifice; this median fold is named the *frenulum* of the prepuce. The prepuce is separated from the glans penis by a potential sac—the *preputial sac*—which presents two shallow fossæ, one on each side of the frenulum. On the corona of the glans and on the neck of the penis there are numerous small *preputial glands*; these secrete a sebaceous material named the *smegma*, which has a characteristic odour.

The *superficial fascia of the penis* is almost entirely devoid of fat and consists of very loosely arranged areolar tissue, in which a few plain muscle fibres (dartos muscle) are present. As in the lower part of the anterior abdominal wall, the deepest layer is membranous in character; it forms the *fascia penis* (or deep fascia of the penis), which surrounds both the corpora cavernosa and the corpus spongiosum and separates the superficial from the deep dorsal vein. It does not extend beyond the neck of the penis, where it blends with the fibrous envelopes of the corpora cavernosa and corpus spongiosum. Proximally, it is continuous with the dartos muscle and the fascia covering the urogenital region of the perineum (p. 607).

FIG. 1246.—A transverse section through the penis.



The weight of the body of the penis is supported by two ligaments, both derived from the fascia of the penis and consisting very largely of elastic fibres. The *fundiform ligament* (fig. 580) springs from the lower part of the linea alba and splits into two lamellæ which pass one on each side of the penis and unite below with the septum of the scrotum. The *suspensory ligament* is deep to the fundiform ligament. It is triangular in shape and is attached, above, to the front of the pubic symphysis. Below, it blends with the fascia penis on each side of the organ.

Structure of the penis.—From the internal surface of the fibrous envelope of the corpora cavernosa penis, as well as from the sides of the septum, numerous *trabeculæ* arise, and cross the corpora cavernosa in all directions, subdividing them into a number of *cavernous spaces*, and giving the entire structure a spongy appearance (fig. 1246). These trabeculæ consist of white fibrous tissue, elastic fibres and plain muscular fibres, and they contain numerous arteries and nerves. The cavernous spaces are filled with blood, and are lined with a layer of flattened endothelial cells.

The fibrous envelope (*tunica albuginea*) of the corpus spongiosum penis is thinner, whiter in colour, and more elastic than that of the corpora cavernosa penis. It is formed partly of unstriated muscular fibres, and a layer of the same tissue surrounds the canal of the urethra.

Vessels and Nerves.—The arteries bringing the blood to the cavernous spaces are the deep arteries of the penis, and branches from the dorsal arteries of the penis, which perforate the fibrous capsule along the upper surface, especially near the extremity of the organ. On entering the cavernous structure the arteries divide into branches which are supported and enclosed by the trabeculæ. Some of these arteries

end in a capillary network, which opens directly into the cavernous spaces; others assume a tendril-like appearance, and form convoluted and somewhat dilated vessels, named *helicine arteries*. They open into the cavernous spaces, and from them small capillary branches go to supply the trabecular structure. They are most abundant in the posterior parts of the corpora cavernosa.

The blood from the cavernous spaces is returned by a series of vessels, some of which emerge from the base of the glans penis and converge on the dorsum of the penis to form the deep dorsal vein; others pass out on the upper surface of the corpora cavernosa and join the same vein; some emerge from the under surface of the corpora cavernosa and, receiving branches from the corpus spongiosum, wind round the sides of the penis to end in the deep dorsal vein; but many pass out at the root of the penis and join the prostatic plexus. (See also p. 869.)

Erection of the penis is a purely vascular phenomenon, independent of muscular compression exerted by the Ischiocavernosi and the Bulbocavernosus. Rapid inflow from the helicine arteries fills the cavernous spaces and the resulting distension of the corpora cavernosa acts as a contributory factor by pressing on the veins which drain the erectile tissue.

The *lymph vessels* are described on p. 907.

The *nerves* are derived from the second, third and fourth sacral nerves, through the pudendal nerve and the pelvic plexuses (p. 1221). On the glans and on the bulb of the penis some filaments of the cutaneous nerves have lamellated corpuscles connected with them, and many of them end in peculiar end-bulbs (p. 920).

THE PROSTATE

The **prostate** (figs. 1232, 1242, 1243) is a firm, partly glandular and partly muscular body, surrounding the commencement of the urethra in the male. It is situated in the pelvic cavity, behind the lower part of the symphysis pubis and the upper part of the pubic arch, and in front of the ampulla of the rectum through the wall of which it may be felt in the living. It is about the size of a chestnut and somewhat conical in shape, and presents for examination a base, an apex, a posterior, an anterior and two inferolateral surfaces.

The *base* is directed upwards, and, for the greater part of its extent, is directly continuous with the neck of the urinary bladder; the urethra enters it nearer its anterior than its posterior border.

The *apex* is directed downwards and is in contact with the fascia on the deep surfaces of the Sphincter urethræ and the Transversus perinei profundus (p. 609).

The *posterior surface* is flattened from side to side and slightly convex from above downwards; it is separated by its sheath and some loose connective tissue from the rectum, and is distant about 4 cm. from the anus (fig. 1232). Near its upper border there is a depression through which the two ejaculatory ducts enter the prostate. This depression serves to divide the posterior surface into a lower, larger, and an upper, smaller part. The upper, smaller part constitutes the *median lobe* of the prostate and intervenes between the ejaculatory ducts and the urethra; it varies greatly in size, and in some cases is destitute of glandular tissue. The lower, larger portion sometimes presents a shallow median furrow, which imperfectly separates it into *right* and *left lobes*; these form the main mass of the gland and are directly continuous with each other behind the urethra; they are connected in front of the urethra by a band which is named the *isthmus*; the latter consists of fibromuscular tissue and is devoid of glandular substance.

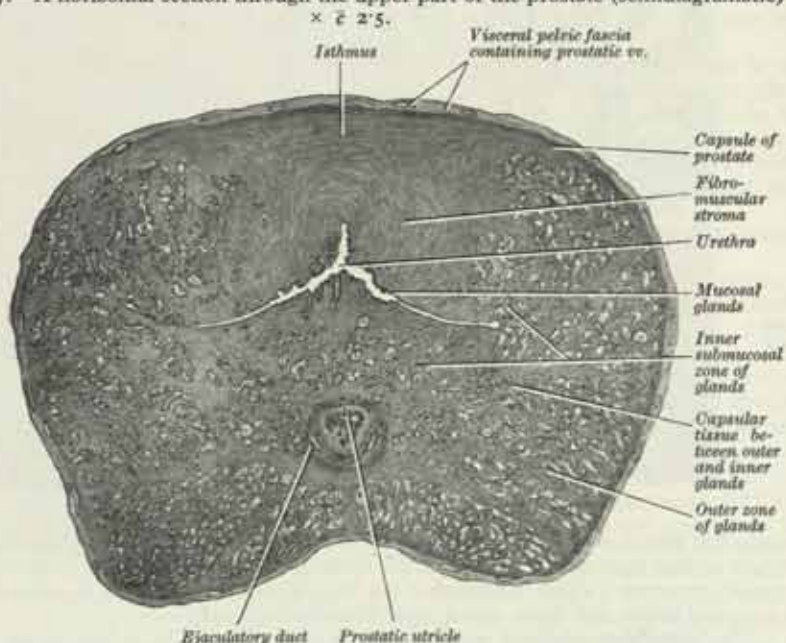
The *anterior surface* is narrow and convex from side to side and extends from the apex to the base. It lies about 2 cm. behind the pubic symphysis, from which it is separated by a plexus of veins and a quantity of loose fatty tissue. Near its upper end it is connected to the pubic bones by the pubo-prostatic ligaments. The urethra emerges from this surface a little above and in front of the apex of the prostate.

The *inferolateral surfaces* are prominent, and are related to the anterior portions of the Levatores ani, which are, however, separated from the gland by a plexus of veins imbedded in fibrous tissue which forms the lateral part of the sheath of the organ.

The prostate measures about 4 cm. transversely at the base, about 2 cm. in its anteroposterior, and 3 cm. in its vertical, diameter. Its weight is about 8 gm. It is invested by a fibrous sheath, which is partly vascular and partly non-vascular. On each side the sheath consists of fibrous tissue in which are imbedded the veins of the prostatic venous plexus (fig. 772). In front, it is continuous with the pubo-prostatic

ligaments (p. 603) and, below, it blends with the fascia on the deep surfaces of the Sphincter urethrae and the Transversus perinei profundus, and with the perineal body (fig. 590). The posterior wall of the sheath has a different constitution and is non-vascular. In the male foetus, at the fourth month, the recto-vesical peritoneal pouch extends downwards to the pelvic floor and separates the prostate from the rectum. The lower part of this recess becomes obliterated and the fused peritoneal layers form the posterior wall of the prostatic sheath.* This fibrous membrane has been termed the *recto-vesical fascia*. Traces of its origin from two original layers are evident for there exists in its central part a plane at which it cleaves readily. Above, it extends upwards over the posterior aspects of the seminal vesicles and the

FIG. 1247.—A horizontal section through the upper part of the prostate (semidiagrammatic)



deferent ducts and is connected to the peritoneal floor of the recto-vesical pouch (fig. 590). On each side, it is connected with the posterior ligament of the bladder (p. 1487) and, below, where it becomes closely adherent to the prostate, it is lost in the perineal body. P. H. Silver (*J. Anat., Lond.*, 1956, **90**, 538), however, finds no evidence of such peritoneal fusion and maintains that the recto-vesical fascia is formed simply by condensation of loose areolar tissue. The anterior portions of the Levatores ani pass backwards from the pubis and embrace the sides of the prostate; from the support afforded to this organ these parts of the muscles are named the *Levatores prostatae*.

The prostate is perforated by the urethra and the ejaculatory ducts and contains the prostatic utricle. The urethra usually lies along the junction of its anterior with its middle one-third. The ejaculatory ducts pass obliquely downwards and forwards through the posterior part of the prostate, and open into the prostatic portion of the urethra (p. 1490).

Structure (figs. 1247 and 1248).—The prostate is enveloped by a thin but firm capsule, distinct from the sheath derived from the pelvic fascia, the latter containing a plexus of veins. This capsule is firmly adherent to the prostate and is structurally continuous with the stroma of the gland, being composed of the same tissues, viz. non-striped muscle and fibrous tissue. The substance of the prostate is of a pale reddish-grey colour, of great density, and not easily torn. It consists of glandular substance and muscular tissue.

The *muscular tissue* constitutes the proper stroma of the prostate, the connective tissue being very scanty, and merely forming, between the muscular fibres, thin trabeculae in which the vessels and nerves of the gland ramify. The muscular tissue is arranged as follows: immediately beneath the capsule there is a dense layer, which forms an investing sheath for the gland: around the prostatic part of the urethra a

* G. Elliot Smith, *J. Anat.*, **42**, 1908.

dense layer of circular fibres is continuous above with the internal layer of the muscular coat of the bladder, and blends below with the fibres surrounding the membranous portion of the urethra; between these two layers strong bands of muscular tissue decussate freely, and form meshes in which the glandular structure of the organ is imbedded. In that part of the gland which is situated in front of the urethra the

FIG. 1248.—Section through prostate, stained with iron haematoxylin and Van Gieson's stain. $\times 100$.



muscular tissue is especially dense, and there is here little or no glandular tissue; while in that part which is behind the urethra the muscular tissue presents a wide-meshed structure, which is densest at the base of the gland—that is, near the bladder—becoming looser and more sponge-like towards the apex.

The *glandular substance* is composed of numerous follicles the lining of which frequently shows papillary elevations. The follicles open into elongated canals which join to form from twelve to twenty small excretory ducts. They are connected together by areolar tissue, supported by prolongations from the fibrous capsule and muscular stroma, and enclosed in a delicate capillary plexus. The epithelium which lines the canals and the follicles is of the columnar variety. The prostatic ducts open into the prostatic sinus in the floor of the prostatic portion of the urethra, and are lined by two layers of epithelium, the inner layer consisting of columnar and the outer of small cubical cells. Small colloid masses, known as amyloid bodies, are often found in the gland tubes. The prostatic secretion and the secretion of the seminal vesicle together form the bulk of the seminal fluid. The prostatic secretion is slightly acid and contains acid phosphatase and fibrolysin.

Histological sections of the prostate (fig. 1247) do not show a lobar pattern of the organ, but two well-defined, concentric zones of glandular tissue, partially surrounding the prostatic urethra, are recognisable.* The larger, *outer zone* is composed of long, branched glands, the ducts of which curve backwards to open mainly into the floor of the prostatic sinuses, though some open into the lateral walls of the urethra. The *inner zone* consists of a set of 'submucosal' glands, the ducts of which open into the floor of the prostatic sinuses, and partly on the colliculus seminalis, and an innermost group of short, simple 'mucosal' glands, which surround the upper part of the prostatic urethra. Anteriorly, in the isthmus of the prostate, the outer zone and the 'submucosal' glands are deficient. The outer and inner zones are separated by an ill-defined, irregular 'capsule.' Carcinoma affects almost exclusively the outer zone, while the inner zone is particularly prone to benign hypertrophy (hyperplasia), probably due to oestrogenic stimulation; this latter growth projects upwards into the bladder and displaces the outer zone backwards and downwards, producing thereby a more distinct 'capsule' between the outer and inner zones, which allows a 'cleavage plane' for the surgical enucleation of the hypertrophic growth.

* L. M. Franks, *Ann. Roy. Coll. Surg., Eng.*, 1954, **14**, 92-106; J. D. Fergusson and E. C. Gibson, *Brit. Med. J.*, 1956, **1**, 822-825; I. E. LeDuc, *J. Urol.*, 1939, **42**, 1217-1241.

Vessels and Nerves.—The *arteries** supplying the prostate are derived from the internal pudendal, inferior vesical and middle rectal arteries. Its *veins* form a plexus around the sides and base of the gland (p. 868); they receive in front the deep dorsal vein of the penis, and end in the internal iliac veins. The *lymph vessels* are described on p. 907. The *nerves* are derived from the pelvic plexus (p. 1221).

Age changes in the prostate.†—At birth the prostate consists of a duct system imbedded in a stroma which constitutes a large part of the bulk of the gland. Follicles are represented by small end-buds on the ducts. There is a hyperplasia and squamous metaplasia of the epithelium of the ducts, the colliculus seminalis, and the prostatic utricle which are possibly due to the action of maternal oestrogens circulating in the foetal blood. These changes settle in about six or seven weeks and then the prostate undergoes little structural change until about the ninth year when there occurs a hyperplasia of the duct epithelium and the formation of side buds leading to an elaboration of the duct system. During the period up to puberty there is a slow and continuous increase in the size of the prostate.

At puberty changes occur very rapidly over a period of about six months to one year. There is rapid increase to more than twice the size of the pre-pubertal gland, due almost entirely to the development of follicles, partly from the end-buds on the ducts, and partly from modification of branches of the ducts. This change is associated with some condensation of the stroma, which becomes reduced in relation to the amount of glandular tissue. These changes are probably due to the secretion of male hormone into the bloodstream by the testis.

During the third decade the glandular epithelium is increased by irregular complication of the infolding of epithelium into the lumen of the follicles.

After the third decade the size remains fairly constant until the age of forty-five to fifty. Infoldings of the epithelium tend to disappear so that the outlines of the follicles are more regular and amyloid bodies increase in number. All these changes indicate the beginning of prostatic involution.

After the age of forty-five to fifty the prostate either may undergo benign hypertrophy so that its size increases gradually until death, or it may progressively atrophy.

Applied Anatomy.—In advanced life the prostate often becomes considerably enlarged and projects into the bladder so as to impede the passage of the urine by elongating and distorting the prostatic urethra. In some cases the median lobe enlarges most, and even a small enlargement of this lobe may act injuriously, by forming a sort of valve over the internal urethral orifice, preventing the passage of the urine; and the more the patient strains, the more completely will it block the opening into the urethra. The hypertrophied part of the gland projecting into the bladder may be removed by the operation of suprapubic prostatectomy, in which, the bladder having been opened, the surgeon inserts his finger through the mucous membrane of the bladder into the plane of separation between the capsule of the prostate and the hypertrophied mass and enucleates the latter. In this way, injury to the prostatic venous plexus is avoided since these veins lie in the prostatic sheath derived from the pelvic fascia. The prostate may also be removed either by a surgical approach from the perineum into the fascial space between the rectum and the prostatic sheath (perineal prostatectomy), or by the operation of retropubic prostatectomy, in which an incision is made through the anterior abdominal wall just above the pubic symphysis, the bladder displaced backwards and the prostate thus exposed.

THE BULBO-URETHRAL GLANDS (fig. 734)

The **bulbo-urethral glands** are two small, rounded and somewhat lobulated bodies, of a yellow colour. Each is about the size of a pea, and is placed lateral to the membranous portion of the urethra, deep to the perineal membrane. They lie above the bulb of the penis, and are enclosed by the transverse fibres of the Sphincter urethræ. They gradually diminish in size as age advances.

The excretory duct of each gland is nearly 3 cm. long; it passes obliquely forwards beneath the mucous membrane, and opens by a minute orifice on the floor of the spongy portion of the urethra about 2.5 cm. below the perineal membrane.

Structure.—Each gland is made up of several lobules which are held together by a fibrous investment. Each lobule consists of a number of acini, lined by columnar epithelial cells. The secretion of the bulbo-urethral glands is an additional constituent of the seminal fluid, but the glands are very small in man as compared with many animals, and the part which they play is probably very subsidiary.

* See E. J. Clegg, *J. Anat., Lond.*, 1955, 89, 209.

† G. I. M. Swyer, *J. Anat., Lond.*, 1944, 78, 130.

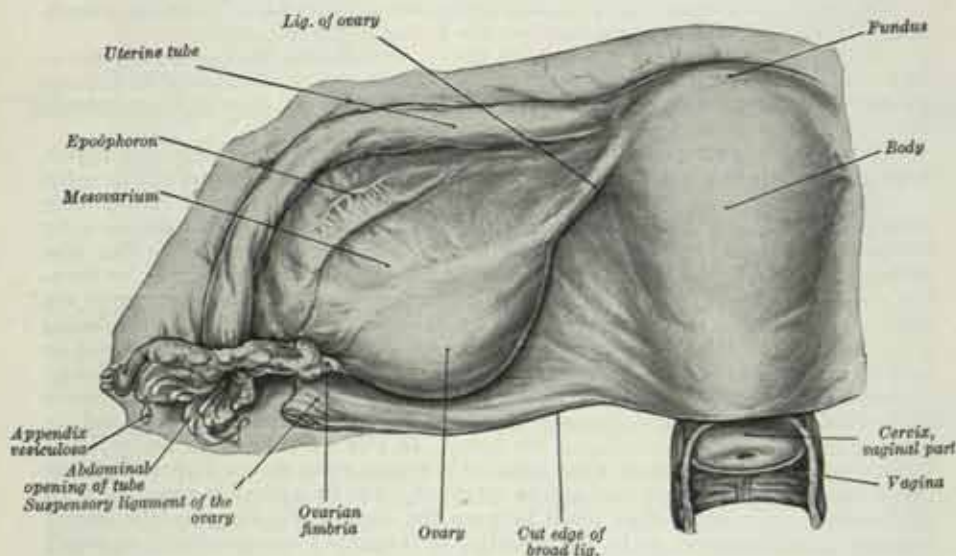
THE FEMALE GENITAL ORGANS

The female genital organs consist of an internal and an external group. The *internal organs* are situated within the pelvis, and are the ovaries, the uterine tubes, the uterus and the vagina. The *external organs* are placed below and in front of the pubic arch. They comprise the mons pubis, the labia majora et minora pudendi, the clitoris, the bulbus vestibuli and the greater vestibular glands.

THE OVARIES (figs. 1249 and 1254)

The **ovaries**, two in number, are homologous with the testes in the male. They are situated one on each side of the uterus in relation to the lateral wall of the pelvis, and attached to the posterior or upper layer of the broad ligament of the uterus, behind and below the uterine tube (fig. 1249). They are of a greyish-pink colour, and present a smooth surface before regular ovulation begins but thereafter the surface is puckered and uneven due to the cicatrization which follows degeneration

FIG. 1249.—The uterus and the left broad ligament. Posterior surface. The broad ligament has been spread out and the ovary drawn downwards.



of the successive corpora lutea. Each ovary is almond-shaped and is about 3 cm. long, 1.5 cm. wide, and about 10 mm. thick. The exact position of the ovary is subject to a wide range of variation in women who have borne children, as it is displaced in the first pregnancy and probably never returns again to its original position. The description here given applies to that of the nulliparous woman. In the erect posture the long axis of the ovary is vertical, and the gland presents a lateral and a medial surface, a tubal and a uterine extremity, and a mesovarian and a free border. The ovary lies in a depression, named the *ovarian fossa*, on the lateral wall of the pelvis; this fossa is bounded in front by the obliterated umbilical artery, and behind by the ureter and the internal iliac artery. The *tubal extremity* is near the external iliac vein; to it are attached the ovarian fimbria of the uterine tube and a fold of peritoneum, named the *suspensory ligament of the ovary*, which contains the ovarian vessels and nerves, and passes upwards over the external iliac vessels to become continuous with the peritoneum on the Psoas major muscle behind the cæcum (fig. 1254) or descending colon. The *uterine extremity* is directed downwards towards the pelvic floor; it is usually narrower than the tubal extremity, and is attached to the lateral angle of the uterus, immediately behind and below the uterine tube, by a rounded cord termed the *ligament of the ovary*, which lies within the broad ligament and contains some non-striped muscular fibres. The *lateral surface* is in contact with the parietal peritoneum which lines the ovarian fossa; it

separates the ovary from the extraperitoneal tissue and the obturator vessels and nerve. The *medial surface* is to a large extent covered with the uterine tube and the peritoneal recess between this aspect of the gland and the mesosalpinx which overlaps it is usually termed the *bursa ovarica*. The *mesovarian border* is straight and is directed towards the obliterated umbilical artery; it is attached to the back of the broad ligament by a short fold named the *mesovarium*. Between the two layers of this fold the blood-vessels and nerves pass to the hilus of the ovary. The *free border* is convex, and is directed towards the ureter. The uterine tube arches over the ovary, running upwards in relation to its mesovarian border, curving over its tubal extremity, and then passing downwards on its free border and medial surface (fig. 1254).

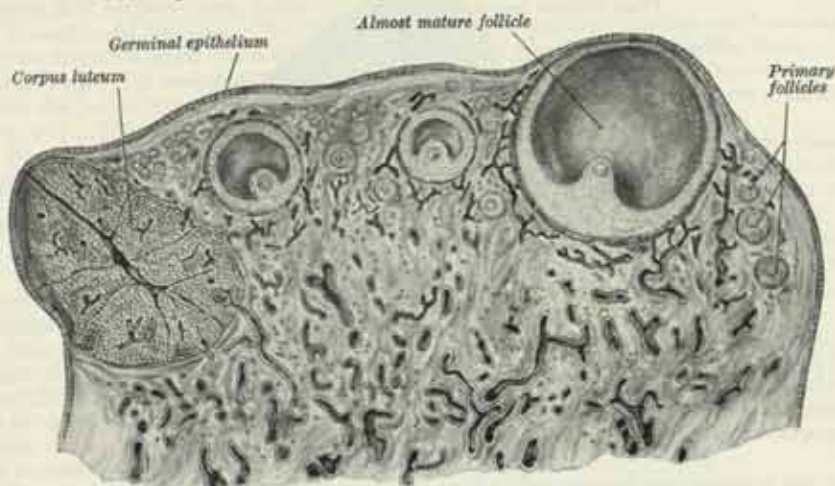
In the fetus, the ovaries are situated, like the testes, in the lumbar region near the kidneys, but they gradually descend into the pelvis (p. 216).

Accessory ovaries may occur, either in the mesovarium or in the adjacent part of the broad ligament.

Structure (fig. 1250).—The surface of the ovary is covered with a layer of cubical cells in the young female, which become flattened later in life. This *germinal epithelium* gives to the ovary a dull grey colour as compared with the shining smoothness of the peritoneum; the transition between the flattened mesothelium of the peritoneum and the cubical cells covering the ovary is usually marked by a fine white line around the anterior, or mesovarian, border of the ovary.

The ovary, after puberty, has a thick cortex which contains the ovarian follicles

FIG. 1250.—A section through the ovary. Semi-diagrammatic.



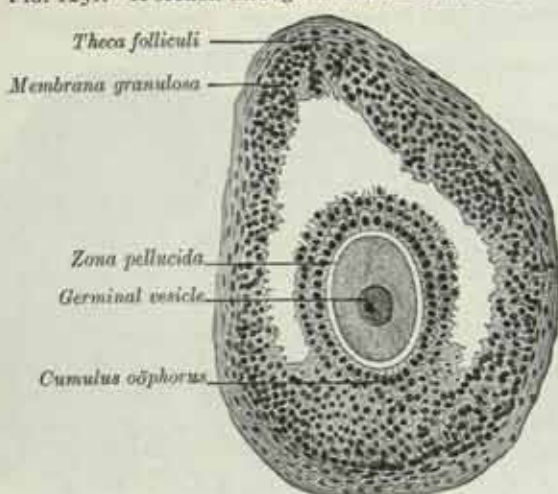
and corpora lutea and surrounds, except at the hilus, a richly vascular medulla. The interstitial framework or *stroma* of the cortex is of a dense texture and consists of networks of reticular connective tissue fibres and numerous spindle-shaped cells which resemble plain muscle cells, though they contain no fibrils. The stroma of the medulla is of a looser texture and consists of connective tissue, with many elastic fibres, some plain muscle cells and numerous large blood vessels, particularly veins. At the hilus, strands of plain muscle cells enter the medulla from the mesovarium. The cortex is much less vascular than the medulla. Immediately beneath the germinal epithelium, the connective tissue of the cortex is condensed to form the *tunica albuginea*. During pre-natal life the stroma of the cortex contains small groups of *interstitial cells*, but after puberty these cells are only present in the theca of atretic ovarian follicles.

Ovarian follicles.—At birth, the cortex of the ovary contains very numerous *primary ovarian follicles*. Each of these consists of a large central cell, the *oögonium*, surrounded by a single layer of small cubical or flattened cells, the *follicular cells*. The pre-natal development of these follicles is described in the Embryology Section, (p. 57). The subsequent fate of these follicles is uncertain. It has been thought that most of them degenerate during childhood and that only relatively few remain dormant until puberty, when some develop each month to form *vesicular ovarian (Graafian) follicles*, one of which usually matures and ruptures (ovulation). There is evidence, however, that all the pre-natal follicles degenerate during childhood and that after puberty new follicles are formed each month as ingrowths from the germinal

epithelium. After puberty, and during the 'child-bearing period' of life (that is, up to the time of the menopause), the cortex contains ovarian follicles and corpora lutea in all stages of development (fig. 1250).

The primary follicle develops into a vesicular follicle in the following manner. The follicular cells multiply and become many layered; a cavity (the *antrum folliculi*) containing fluid (the *liquor folliculi*) appears between the cells and separates them into two collections. The outer set form the *membrana granulosa* and the inner set, which surround the ovum and attach it to one pole of the follicle, form the *cumulus oöphorus* (fig. 1251). The stromal cells of the cortex of the ovary form a sheath (the *theca folliculi*) around the follicle and this sheath is differentiated into an inner part, the *tunica interna*, which is cellular in character and permeated by a capillary plexus, and an outer part, the *tunica externa*, which is fibrous in character. The *tunica interna* is separated from the *membrana granulosa* by a delicate basement membrane, and as the follicle is approaching its full development, the *tunica interna* becomes well-defined and constitutes the 'thecal gland'. The cells of the *tunica interna* and those of the *membrana granulosa* produce oestrogenic hormone (oestradiol), and the development of the follicle itself is stimulated by the gonadotrophic hormone of the hypophysis cerebri (follicle stimulating hormone; F.S.H.). Meanwhile the oögonium in the primary follicle becomes converted into a primary oöcyte, and the latter divides into a secondary oöcyte and a first polar body. When the fully developed vesicular ovarian follicle ruptures (ovulation), it is the secondary oöcyte which is extruded, and the second polar body is not formed unless fertilisation takes place.

FIG. 1251.—A section through an ovarian follicle of a cat. $\times 50$



A fully developed follicle is 10 mm. or more in diameter. As a rule, only one follicle fully matures and ruptures in each monthly menstrual cycle; in some cycles ovulation may not occur (anovulatory cycles). However, several other primary follicles also develop to varying extents to form small vesicular follicles, but they undergo degeneration (atretic follicles) and the cells of the *tunica interna* of each form the interstitial cells of the ovary.

Ovulation.—When the fully ripened vesicular follicle ruptures on the surface of the ovary, the secondary oöcyte, surrounded by follicular cells of the *cumulus oöphorus*, is normally expelled and passes into the uterine tube along its fimbriated end. If fertilisation occurs, it normally takes place in the lateral third of the uterine tube. If fertilisation does not occur, the oöcyte begins to degenerate after a short time (24–48 hours). Ovulation most frequently occurs 12 to 16 days before the anticipated onset of the next menstrual cycle, though it may occur outside these limits.

Corpus luteum.—After ovulation, the wall of the vesicular ovarian follicle collapses and becomes folded, the cells of the *membrana granulosa* become greatly increased in size and a yellowish carotenoid pigment (lutein) is formed in their cytoplasm. These cells are called luteal cells and they form the major part of the *corpus luteum* (fig. 1250). Some smaller cells (paraluteal cells), derived from the cells of the *tunica interna*, also lie on and between the superficial luteal cells. Blood capillaries grow in from the vessels in the *tunica interna* and lie between the luteal cells. A little blood clot occupies the interior of the corpus luteum. If fertilisation does not occur, the corpus luteum has a functional life of about 12 to 14 days, after which it shows progressive degenerative changes. Such a corpus luteum is known as a *corpus luteum of menstrua-*

tion. The degenerative changes include fatty degeneration of the luteal cells and their gradual replacement by fibrous tissue (corpus albicans), so that eventually, after a period of about two months, only a small fibrous cicatrix remains. The synergic activities of the hypophyseal gonadotrophic hormones—follicle stimulating hormone (F.S.H.), luteinising hormone (L.H.) and luteotrophic hormone (L.T.H., or prolactin, or lactogen)—are responsible for the conversion of the granulosa cells into luteal cells. The luteal cells produce the hormone progesterone, and both the luteal and paraluteal cells produce some oestradiol. The action of these ovarian hormones (progesterone and oestradiol) on the endometrium of the uterus will be described later (p. 1517).

If pregnancy occurs, implantation of the blastocyst in the uterine endometrium normally begins on the seventh day following fertilisation, and the trophoblast produces hormones (follicle stimulating hormone, luteinising hormone, progesterone and oestradiol). These follicle stimulating and luteinising hormones are known as chorionic gonadotrophins and they stimulate the corpus luteum of menstruation to increase in size and prolong its activity. Such a corpus luteum is known as a *corpus luteum of pregnancy*. Whereas the corpus luteum of menstruation is active for only about 12 to 14 days and usually is about 1 cm. in diameter, the corpus luteum of pregnancy increases in size to reach about 2.5 cm. in diameter about the middle of pregnancy and remains active until late in pregnancy. By the end of pregnancy it is reduced to about 1 cm. in diameter and gradually, over a period of some months, undergoes the same degenerative changes as occur in the corpus luteum of menstruation.

As the female becomes older, the ovary becomes more and more fibrotic due to the formation of the corpora albicantia and, after the menopause, which occurs usually near the age of fifty years, the above changes in the ovary, involving the formation of follicles and corpora lutea, cease.

Vessels and Nerves.—The arteries of the ovaries and uterine tubes are the ovarian arteries from the aorta (p. 806). The veins emerge from the hilus in the form of a plexus, named the *pampiniform plexus*; the ovarian vein is formed from this plexus, and leaves the pelvis in company with the artery (p. 873). The lymph vessels are described on p. 907. The nerves are derived from the ovarian plexus (p. 1217).

Epoöphoron (fig. 1249).—The epoöphoron lies in the lateral part of the mesosalpinx between the ovary and the uterine tube, and consists of 10 to 15 short tubules, the *transverse ductules* of the epoöphoron, which converge towards the ovary and end blindly, while their other ends open into a rudimentary duct, the *longitudinal duct of the epoöphoron*, which runs medially in the broad ligament of the uterus, parallel with the lateral part of the uterine tube. Frequently, between the epoöphoron and the fimbriated end of the uterine tube, one or more small cysts are present (the *appendices vesiculosae*).

In a small proportion of subjects the longitudinal duct of the epoöphoron can be followed alongside the uterus to near the level of the internal os. Here it pierces the muscular wall of the uterus and descends in the cervix uteri, gradually approaching the mucous membrane, without however quite reaching it. The duct then runs downwards in the lateral wall of the vagina and ends at, or close to, the free margin of the hymen.

Paroöphoron.—The paroöphoron consists of a few scattered rudimentary tubules, best seen in the child, situated in the broad ligament between the epoöphoron and the uterus.

The tubules of the epoöphoron and of the paroöphoron are remnants of the tubules of the mesonephros; the duct of the epoöphoron is a persistent portion of the mesonephric duct (p. 207).

THE UTERINE TUBES (figs. 1249, 1253)

The **uterine tubes**, two in number, transmit the ova from the ovaries to the cavity of the uterus, and are situated in the upper margins of the broad ligaments of the uterus. Each tube is about 10 cm. long, and one end of it opens into the superior angle of the cavity of the uterus, the other into the peritoneal cavity close to the ovary. The opening into the uterine cavity is very small, and admits only a fine bristle; the opening into the peritoneal cavity is named the *abdominal opening*, and when its muscular wall is relaxed has a diameter of about 3 mm. The abdominal opening is situated at the bottom of a trumpet-shaped expansion of the uterine tube, termed the *infundibulum*, the circumference of which is prolonged into a varying number of irregular processes, called *fimbriae*, and therefore this extremity of the tube is sometimes called the *fimbriated end*. The inner surfaces of the fimbriae are lined by mucous membrane, and in the larger fimbriae this exhibits longitudinal folds which are continuous with similar folds in the mucous lining of the infundibulum. One fimbria, longer and more deeply grooved than the others, is attached

to the tubal extremity of the ovary, and is named the *ovarian fimbria*. The infundibulum opens into the *ampulla* of the tube, which is thin-walled and tortuous and forms rather more than one-half the entire length of the tube. The ampulla is succeeded by the *isthmus*, which is round and cord-like and constitutes approximately the medial one-third of the tube. The part continued from the isthmus through the wall of the uterus is about 1 cm. long, and is named the *pars uterina tubæ*.

The uterine tube is directed laterally as far as the uterine extremity of the ovary, and then ascends along the mesovarian border to the tubal extremity of the ovary, over which it arches; finally it turns downwards and ends in relation to the free border and medial surface of the ovary. In connexion with the fimbriæ of the uterine tube, or with the broad ligament close to them, there are frequently one or more small pedunculated vesicles; these are termed the *appendices vesiculosæ* (fig. 1249).

Structure (fig. 1252).—The uterine tube consists of three coats: serous, muscular and mucous. The *external*, or *serous*, coat is peritoneal. The *middle*, or *muscular*, coat

FIG. 1252.—Transverse section of a human uterine tube (ampulla).
Stained with hæmatoxylin and eosin. $\times 15$.



consists of an external longitudinal and an internal circular layer of non-striped muscular fibres continuous with those of the uterus. The *internal*, or *mucous*, coat is continuous with the mucous lining of the uterus. It is thrown into longitudinal folds, which in the ampulla are much more extensive than in the isthmus. The lining epithelium is columnar and ciliated. This form of epithelium is also found on the inner surfaces of the fimbriæ; while on the outer or serous surfaces of these processes the epithelium gradually merges into the mesothelium of the peritoneum.

Applied Anatomy.—Pelvic peritonitis occurs much more frequently in the female than in the male, because infective conditions of the vagina, uterus or uterine tube may involve the peritoneum by direct spread, owing to the communication which exists between the peritoneal cavity and the lumen of the tube through the abdominal opening. When pus collects in the recto-uterine pouch, it may be palpated through the posterior fornix of the vagina, on account of the peritoneal relations of the upper part of the posterior vaginal wall (p. 1520).

Tubal inflammation (*salpingitis*) is usually due to infections which have spread upwards by way of the vagina and uterus. In many cases the fimbriated end of the tube may become closed by adhesions and a collection of pus forms in the tube (*pyosalpinx*).

Fertilisation of the ovum (p. 63) occurs in the ampulla of the uterine tube, and the fertilised ovum normally is then passed on into the uterus; the ovum, however, may adhere to and undergo development in the tube, giving rise to the commonest variety

of *ectopic gestation*. In such cases the amnion and chorion are formed, but a true decidua is never present; and the gestation usually ends by extrusion of the ovum through the abdominal opening, although it is not uncommon for the tube to rupture into the peritoneal cavity, this being accompanied by severe hæmorrhage, and necessitating surgical interference.

THE UTERUS (figs. 1249, 1253, 1254)

The **uterus**, or **womb**, is a hollow, thick-walled, muscular organ situated in the pelvic cavity between the urinary bladder in front and the rectum behind. Into its upper part the uterine tubes open, one on each side, while below, its cavity communicates with that of the vagina. When the ova are discharged from the ovaries they are carried to the uterine cavity through the uterine tubes. If an ovum be fertilised it imbeds itself in the uterine wall and is normally retained in the uterus until prenatal development is completed, the uterus undergoing changes in size and

FIG. 1253.—A female pelvis and its contents. Viewed from above and in front.



structure to accommodate itself to the needs of the growing embryo. After parturition the uterus returns almost to its former condition, but traces of its enlargement remain. For general descriptive purposes the adult virgin uterus is taken as the type form.

In the *virgin state* the uterus is flattened from before backwards and is pyriform in shape, with the narrow end directed downwards and backwards. It lies between the bladder below and in front, and the sigmoid colon and rectum above and behind, and is completely below the level of the pelvic inlet.

The long axis of the uterus usually lies approximately in the axis of the pelvic inlet (p. 405), but as the organ is freely movable its position varies with the state of distension of the bladder and rectum. Except when much displaced by a distended bladder, it forms an angle with the vagina, since the axis of the vagina corresponds to the axes of the cavity and outlet of the pelvis (p. 405).

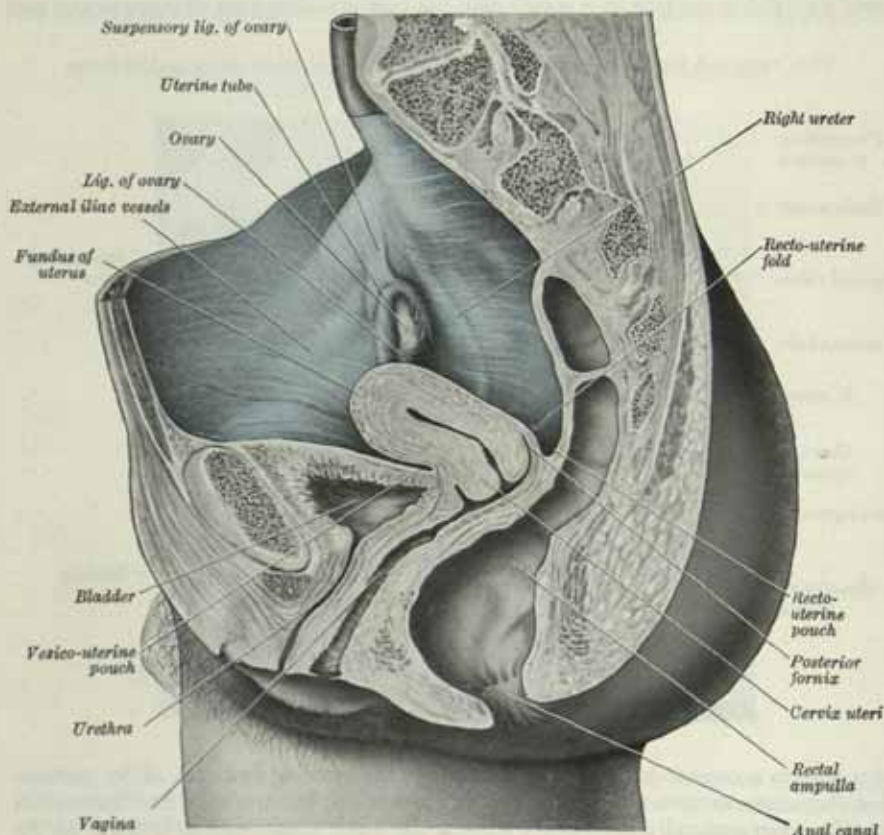
The uterus measures about 7.5 cm. in length, 5 cm. in breadth at its upper part, and nearly 2.5 cm. in thickness; it weighs from 30 to 40 gm. It is divisible into two portions. On the surface, a little below the middle, there is a slight constriction, which corresponds to a narrowing of the uterine cavity, named the *internal os* of the uterus. The portion above the internal os is termed the *body*, and that below, the *cervix*. The part of the body which lies above a plane passing through the points of entrance of the uterine tubes is known as the *fundus*.

Body.—The body gradually narrows from the fundus to the internal os.

The *vesical*, or *anterior*, surface is in apposition with the urinary bladder. It is flattened and covered with peritoneum, which is reflected on to the bladder as the utero-vesical fold at the level of the internal os. The recess or pouch between the bladder and the uterus is named the *vesico-uterine pouch*.

The *intestinal*, or *posterior*, surface is convex transversely, and is covered with peritoneum, which is continued downwards on the cervix uteri and the upper part of the vagina before being reflected backwards on to the rectum (fig. 1254). It is in relation with the sigmoid colon, from which it is usually separated by the terminal coil of the ileum.

FIG. 1254.—A median sagittal section through the female pelvis. The peritoneum is shown in blue.



The *fundus* is convex in all directions, and covered with peritoneum continuous with that on the vesical and intestinal surfaces. Some coils of small intestine, and occasionally the distended sigmoid colon rest on it.

The *margins* are slightly convex. At the upper end of each the uterine tube pierces the uterine wall. Below and in front of this point the round ligament of the uterus is fixed; below and behind it the ligament of the ovary is attached. These three structures lie within a fold of peritoneum, named the broad ligament, which stretches from the margin of the uterus to the lateral wall of the pelvis.

Cervix.—The cervix is about 2.5 cm. in length; it is narrower and more cylindrical than the body, and is a little wider in the middle than above or below. Owing to its relationships it is less freely movable than the body, so that its long axis is seldom in the same straight line as that of the body. The long axis of the uterus as a whole presents the form of a curved line with its concavity forward, and the organ is described as being *anteflexed*. In extreme cases there may be an angular bend at the region of the internal os—acute anteflexion. When the bladder is empty

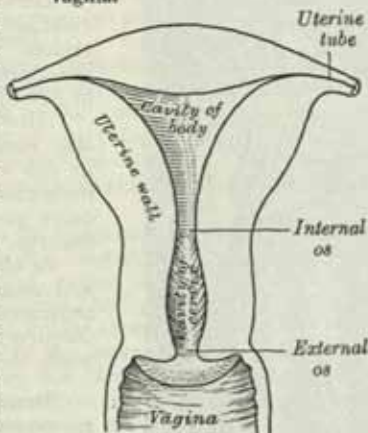
the long axis of the cervix meets the long axis of the vagina at an angle which is open forwards and downwards, and the whole uterus is therefore turned forwards on the vagina, or *anteverted*.

The cervix projects through the anterior wall of the vagina, which divides it into an upper, supravaginal portion, and a lower, vaginal portion (fig. 1254).

The *supravaginal portion* is separated in front from the bladder by cellular tissue (*parametrium*), which extends also on to the sides of the cervix, and laterally between the layers of the broad ligaments. The uterine arteries reach the margins of the cervix in this tissue, while on each side the ureter runs downwards and forwards in it at a distance of about 2 cm. from the cervix. Posteriorly the supravaginal cervix is covered with peritoneum, which is prolonged below on to the posterior vaginal wall, whence it is reflected to the rectum, forming the recto-uterine pouch (p. 1403). It is in relation with the rectum, from which it may be separated by the terminal coil of the ileum.

The *vaginal portion* of the cervix projects into the anterior wall of the vagina between the vaginal fornices (p. 1520). On its projecting rounded extremity there is a small, depressed, somewhat circular aperture, termed the *external os of the uterus*, through which the cavity of the cervix communicates with that of the vagina. In women who have borne children the external os is bounded by two lips, an anterior and a posterior, of which the anterior is the shorter and thicker, although, on account of the slope of the cervix, it projects lower than the posterior. Normally both lips are in contact with the posterior vaginal wall.

FIG. 1255.—The posterior half of the uterus and upper part of the vagina.



Interior of the uterus (fig. 1255).—The cavity of the uterus is small in comparison with the size of the organ.

The *cavity of the body* is a mere slit in sagittal section because the anterior and posterior walls are almost in contact. In coronal section it is found to be triangular in shape, the base being formed by the internal surface of the fundus between the orifices of the uterine tubes, the apex by the internal os of the uterus; through this orifice the cavity of the body communicates with the canal of the cervix.

The *canal of the cervix* is somewhat fusiform, flattened from before backwards, and broader at the middle than at the ends. It communicates above, through the internal os, with the cavity of the body, and below, through the external os, with the vaginal cavity. A longitudinal ridge is present on both the anterior wall and the posterior wall of the canal and from each of these ridges a number of small oblique columns, named the *palmate folds*, proceed, giving the appearance of branches from the stem of a tree; to this arrangement the name *arbor vite uteri* is applied. The folds on the two walls are not opposed, but fit between one another so as to close the cervical canal.

The total length of the uterine cavity from the external os to the fundus is about 6 cm.

According to H. Stieve,* the upper third or less of the cervix, which has been termed the *isthmus*, presents certain features which differentiate it from the rest. He has pointed out that, although it is unaffected in the first month of pregnancy, it is gradually taken up into the body of the uterus during the second month and forms the 'lower uterine segment' of English obstetricians. The fetal membranes, though firmly blended with the rest of the uterine mucosa, are not attached to the lower uterine segment. In the non-pregnant uterus the isthmus undergoes changes associated with menstruation similar to, but less pronounced than those which occur in the body of the organ. Histologically the isthmus resembles the body more than it resembles the cervix; its lining epithelium is low cylindrical in type and is ciliated; its mucous coat is thinner; and the glands are fewer in number.

* H. Stieve, "Der Halsteil der menschlichen Gebärmutter," Leipzig, 1927. See also O. Frankl, *Journal of Obstetrics and Gynecology of the British Empire*, 40, 1933.

FIG. 1256.—Section of the whole thickness of human endometrium in the premenstrual phase. Note the irregular saw-toothed appearance of the walls of the glands and the frayed appearance of the epithelial cells. $\times 60$. Stained with hæmatoxylin and eosin. Kindly lent by the Shattock Museum, St. Thomas's Hospital Medical School.



Changes affecting the uterus.—The form, size and situation of the uterus vary at different periods of life and in different circumstances.

In the fetus the uterus projects above the inlet of the pelvis. The cervix is considerably larger than the body.

At puberty the uterus is pyriform in shape, and weighs from 14 to 17 gms. The fundus is just below the level of the inlet of the pelvis. The palmate folds are distinct, and extend to the upper part of the cavity.

The position of the uterus *in the adult* is liable to considerable variation, depending chiefly on the condition of the bladder and rectum. When the bladder is empty the entire uterus is directed forwards, and is at the same time bent on itself at the junction of the body and cervix, so that the body lies upon the bladder. As the latter fills, the uterus gradually becomes more and more erect, until with a fully distended bladder the fundus may be directed towards the sacrum.

During menstruation the organ is enlarged, and more vascular, and its surfaces are rounder; the external os is rounded, its lips swollen, and the lining membrane of the body is thicker, softer and of a darker colour.

During pregnancy the uterus becomes enormously enlarged, and in the eighth month reaches the epigastric region. The increase in size is partly due to growth of pre-existing muscular fibres, and partly to development of new fibres.

After parturition the uterus nearly regains its usual size, weighing about 42 gm.; but its cavity is larger than in the virgin state, its vessels are tortuous, and its muscular layers are more defined; the external os is more prominent, and its edges present one or more fissures.

In old age the uterus becomes atrophied, and paler, and denser in texture; a more distinct constriction separates the body and cervix. The internal os is frequently, and the external os occasionally, obliterated, while the lips almost entirely disappear.

Structure.—The uterus is composed of three coats: an external or serous, a middle or muscular, and an internal or mucous.

The *serous coat* (or *perimetrium*) is derived from the peritoneum which posteriorly covers the body and supravaginal part of the cervix, but in front covers the body only. In the lower one-fourth of the intestinal surface the peritoneum is not closely connected with the uterus, being separated from it by a layer of loose cellular tissue and some large veins.

The *muscular coat* (or *myometrium*) forms the chief bulk of the substance of the uterus. In the virgin it is dense, firm, of a greyish colour, and cuts almost like cartilage. It is thick opposite the middle of the body and fundus, and thin at the orifices of the uterine tubes. It consists of bundles of unstriped muscular fibres, intermixed with areolar tissue, blood-vessels, lymph vessels and nerves. During pregnancy the muscular tissue becomes more prominently developed, the fibres being greatly enlarged. Although the unstriped muscular fibres interlace in all directions, they are arranged in three more or less distinct layers: external, middle and internal. The muscle coat of the cervix contains more fibrous and elastic tissue than that of the body.

The external layer consists chiefly of longitudinal fibres, which pass over the fundus, and, converging at the lateral angle on each side of the uterus, are continued on the uterine tube, the round ligament and the ligament of the ovary; some passing at each side into the broad ligament, and others running backwards from the cervix

into the uterosacral ligaments. The middle layer of fibres is the thickest, but presents no regularity in its arrangement, being disposed longitudinally, obliquely and transversely; it contains the larger blood-vessels. The internal layer consists of longitudinal and circular fibres. The deep ends of the uterine glands come into close relation with the fibres of the internal layer.

The *mucous membrane* (or *endometrium*) (fig. 1256), lines the uterus, and is continuous, through the fimbriated extremities of the uterine tubes, with the peritoneum, and, through the external os of the uterus, with the linings of the vagina.

In the body of the uterus the mucous membrane is smooth and of pale red colour, and its free surface is covered with columnar epithelium. Prior to puberty the epithelium is ciliated, but owing to its periodic destruction in the process of menstruation and pregnancy it is usually non-ciliated over large areas in the adult uterus. The mucosa consists of an embryonic nucleated and highly cellular form of connective tissue in which run blood-vessels and numerous lymphatic spaces. It contains many tube-like *uterine glands*, which are lined with ciliated columnar epithelium and open into the cavity of the uterus.

CYCLICAL CHANGES IN THE UTERINE MUCOSA (figs. 101-105)

The significance of these changes is described and figured on (pp. 92-95).

During the reparative phase, for about seven days after the cessation of a menstrual flow, the cells of the uterine mucosa show great activity which is evidenced by the presence of many mitotic figures. The glands are straight and narrow, but secretion is beginning to accumulate in the lumen. During the later part of this period thickening of the mucosa ceases and it becomes quiescent.

During the period following ovulation further thickening occurs which is due mainly to accumulation of gland secretion and the extravasation of fluid into the stroma of the mucosa. The glands, especially in the middle zone of the mucosa, become dilated and tortuous and the glandular epithelial cells more flattened in shape. There is marked increase in vascularity of the superficial one-third which, instead of containing only capillaries and venules as in the reparative phase, is invaded by tortuous arterioles from the deeper planes.

In the premenstrual phase,* for a day or two the coiled arterioles in the superficial third of the mucosa become constricted and this, together with the consequent reduction in the amount of tissue fluid produced, causes some shrinkage to occur. The cells in the stroma become more numerous and closely packed. Finally, for a few hours, the circulation in the superficial zone ceases altogether.

As an immediate prelude to the menstrual flow the superficial vessels dilate again, become engorged with blood and finally burst, so that blood burrows into the stroma and under the epithelium. Instead of clotting, the blood goes on accumulating and eventually bursts through the necrotic epithelium which is shed with it, leaving a raw surface. The amount of tissue shed, although variable, always involves a considerable part of the stratum spongiosum (p. 92) and may include about two-thirds of the total thickness of the mucosa. The deeper parts of the mucosa have not been anæmic and remain normal. Later the epithelium migrates from the mouths of the torn glands to re-cover the raw surface, a superficial capillary circulation is re-established for its nutrition and a new reparative phase begins.

The changes in the endometrium during the menstrual cycle thus normally comprise three essential phases. The first phase is the breakdown or 'bleeding' phase; its duration is 3 to 6 days and during it the stratum compactum and most of the stratum spongiosum become necrotic and the endometrium is reduced to about 0.5 mm. in thickness. This is followed by the pre-ovulatory (or follicular) phase, in which, under the stimulating action of œstrogenic hormone (œstradiol) produced by the ovarian follicles, the endometrium is repaired and increases in thickness, though the glands contain very little secretion and are straight and narrow. The third phase is the post-ovulatory (or progestational, or secretory, or premenstrual) phase, in which, due to the synergic action of progesterone and œstradiol produced by the corpus luteum, the endometrium is further thickened to reach a thickness of 5 mm. to 7 mm., and the glands become dilated, tortuous and filled with secretion which is rich in glycogen and mucin. When the corpus luteum ceases to function, the endometrium breaks down, apparently due to the cessation of the stimulating action of progesterone and œstradiol, and the next menstrual cycle thus commences. If pregnancy occurs, the chorionic gonadotrophins (p. 1511) prolong the activity of the corpus luteum and consequently the endometrium does not break down but becomes even more thickened to form the decidua of pregnancy. In the absence of ovulation (anovulatory cycles), no progesterone is produced and the endometrium does not show the characters of the secretory (post-ovulatory) phase; at the end of such a cycle the breakdown of the endometrium is due to the cessation of activity of the ovarian follicle ('œstrogen—

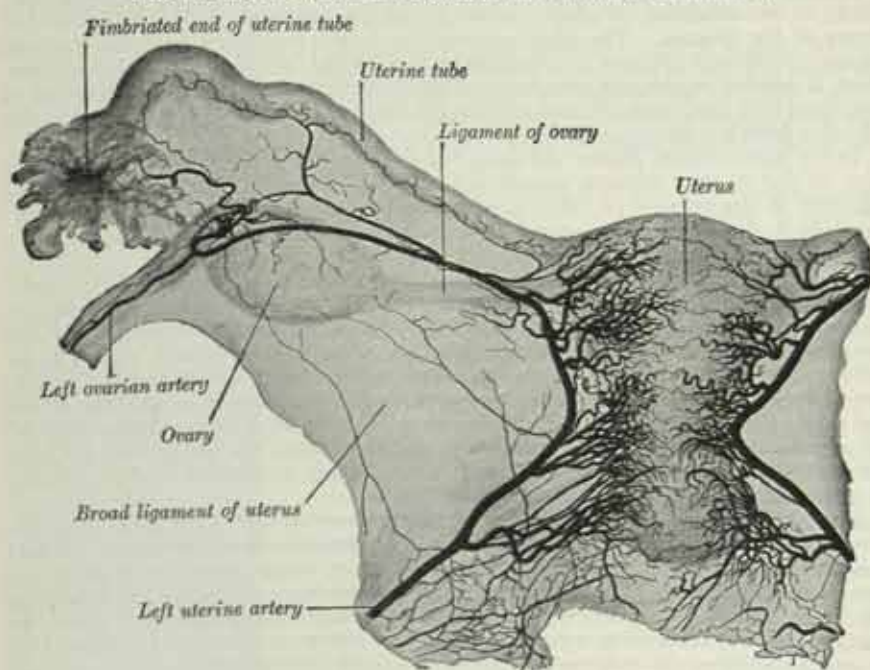
* Consult G. W. Bartelmez, *Contributions to Embryology*, 24, 1933.

withdrawal bleeding'). The mucous membrane lining the cervix of the uterus does not undergo the above cyclical changes.

In the upper two-thirds of the cervix, the mucous membrane is provided with numerous, deep, glandular follicles which secrete a clear, viscid, alkaline mucus; and in addition, extending through the whole length of the canal a variable number of little cysts are found, presumably follicles which have become occluded and distended with retained secretion. They are called the *ovula Nabothi*. The mucous membrane covering the lower one-half of the cervical canal presents numerous papillae. The epithelium of the upper two-thirds is cylindrical and ciliated, but below this it loses its cilia, and, close to the external os, changes to stratified squamous. On the vaginal surface of the cervix the epithelium is similar to that lining the vagina, viz. stratified squamous.

Vessels and Nerves.—The arteries of the uterus are the uterine branch of the internal iliac artery (p. 809), and the ovarian branch of the abdominal aorta (p. 806). They are remarkable for their tortuous course in the substance of the organ (fig. 1257). The termination of the ovarian artery meets that of the uterine artery, and forms an anastomotic trunk from which branches are given off to supply the uterus. The veins are of large size, and correspond with the arteries. They end in the uterine venous plexuses. In the impregnated uterus the arteries carry the blood to, and the veins convey it away from, the intervillous space of the placenta (fig. 108). The lymph vessels are described on p. 907. The nerves are derived from the hypogastric and ovarian plexuses, and from the pelvic splanchnic nerves (S 2, 3, and 4); they are described on p. 1221.

FIG. 1257.—The left uterine and ovarian arteries of an unmarried girl of 17½ years. Posterior aspect. (From a preparation by Hamilton Drummond.)



Applied Anatomy.—A certain amount of anteversion or retroversion of the uterus can take place without the conditions being regarded as pathological, but when the degree of flexion at the junction of the body with the cervix becomes considerable it must be regarded as a morbid condition. This is especially true of retroversion combined with retroflexion. Retroversion alone is falling back of the whole uterus, so that the cervix points forwards towards the os pubis; retroflexion is a bending backwards of the body, at its junction with the cervix. The two conditions are usually combined. Prolapse of the uterus is another common infirmity. The organ sinks to an abnormally low level in the pelvis, and sometimes protrudes beyond the vulva. This condition is usually due to imperfect repair of the pelvic floor following a tear of the perineum during parturition (p. 605).

Ligaments.—The uterus is connected to the bladder, the rectum and the walls of the pelvis by a number of ligaments; some of these are peritoneal ligaments or folds, while others consist of unstriated muscle and fibrous tissue,

The *anterior ligament* consists of the *utero-vesical fold* of peritoneum, which is reflected on to the bladder from the front of the uterus, at the junction of the cervix and body.

The *posterior ligament* consists of the *recto-vaginal fold* of peritoneum, which is reflected from the back of the posterior fornix of the vagina on to the front of the rectum. It forms the bottom of a deep pouch called the *recto-uterine pouch* which is bounded in front by the posterior wall of the body of the uterus, the supravaginal portion of the cervix uteri and the posterior fornix of the vagina; behind, by the rectum; and laterally, by two crescentic folds of peritoneum which pass backwards from the cervix uteri, one on each side of the rectum, to the posterior wall of the pelvis. These folds are named the *recto-uterine folds*. They contain a considerable amount of fibrous tissue and non-striped muscular fibres, which are attached to the front of the sacrum and constitute the *utero-sacral ligaments*. On rectal examination the utero-sacral ligaments can be identified as they pass backwards at the sides of the rectum.

The *two broad ligaments* (fig. 1249) pass from the margins of the uterus to the lateral walls of the pelvis. Together with the uterus they form a septum across the female pelvis, dividing that cavity into two portions. The anterior part contains the bladder; the posterior part, the rectum, and usually, the terminal coil of the ileum and a part of the sigmoid colon.

When the bladder is empty or only slightly distended, the surfaces of the broad ligament are directed upwards and downwards and it has a free anterior and an attached posterior border. As the bladder fills, the plane of the ligament alters and its free border becomes superior in position. In this condition of the bladder, the broad ligament consists of anterior and posterior layers, which are continuous with each other at its upper, free border, and diverge from each other below, where they reach the Levator ani muscle. The uterine tube is contained in the free border and the adjoining part of the ligament is termed the *mesosalpinx*. The infundibulum of the tube projects from the free border near its lateral extremity. The ovary is attached to the posterior layer by the mesovarium. The portion of the broad ligament which extends from the infundibulum of the tube and the upper pole of the ovary to the lateral wall of the pelvis contains the ovarian blood-vessels, nerves and lymph vessels and is termed the *suspensory ligament of the ovary*. It is continued laterally over the external iliac vessels as a distinct fold. Between the ovary and the uterine tube, the mesosalpinx contains the epoöphoron (p. 1511) and, at its medial end, the paroöphoron (p. 1511) and anastomosing branches of the uterine and ovarian vessels. The uterine artery insinuates itself between the layers of the broad ligament at its inferior border, about 1.5 cm. lateral to the cervix and after it has crossed the ureter (p. 1481). It then ascends in the medial part of the ligament and turns laterally below the uterine tube to anastomose with the ovarian artery. In addition to all the structures already enumerated, the broad ligament encloses the ligament of the ovary (p. 1508), the proximal part of the round ligament of the uterus and some unstriped muscle and fibro-areolar tissue.

The *round ligaments* (fig. 1253) are two narrow, flat bands between 10 cm. and 12 cm. long, situated between the layers of the broad ligament in front of and below the uterine tubes. Commencing at the lateral angle of the uterus each ligament is directed forwards and laterally across the vesical vessels, the obturator vessels and nerve, and the obliterated umbilical artery and over the external iliac vessels. It then passes through the deep inguinal ring, hooking round the commencement of the inferior epigastric artery, and traverses the inguinal canal to reach the labium majus, in which it is lost. The round ligament consists principally of muscular tissue prolonged from the uterus, but also contains some areolar tissue. It is accompanied by blood-vessels, lymph vessels and nerves, and in the fœtus a tubular process of the peritoneum [*processus vaginalis*] is carried with it for a short distance into the inguinal canal. The processus vaginalis is generally obliterated in the adult, but sometimes remains pervious even in advanced life. It corresponds to the processus vaginalis which precedes the descent of the testis.

The round ligament and the ligament of the ovary are together homologous with the gubernaculum testis in the male.

In addition to the ligaments just described, there is a band sometimes named the *ligamentum transversale colli* (Mackenrodt) on each side of the cervix uteri. It is attached to the side of the cervix uteri and to the vault and lateral fornix of the

vagina, and is continuous with the fibrous tissue which surrounds the pelvic blood-vessels, probably playing a considerable part in maintaining the position of the uterus. Other dense parts of the pelvic fascia connect the cervix of the uterus and the upper part of the vagina to the back of the pubis.

While the above ligaments (as well as the vagina) act as 'supports' for the uterus, maintaining it in its normal position, the Levator ani and Coccygeus muscles, the muscles of the Urogenital diaphragm and the perineal body are of particular importance in this respect.

THE VAGINA (fig. 1254)

The **vagina** is a canal which extends from the vestibule, or cleft between the labia minora, to the uterus, and is situated behind the bladder and in front of the rectum; it is directed upwards and backwards, its axis forming with that of the uterus an angle of over ninety degrees, opening forwards, but the angle varies with the conditions of the bladder and rectum. Its walls are ordinarily in contact, and the usual shape of its lower part on transverse section is that of an **H**, the transverse limb being slightly curved forwards or backwards, while the lateral limbs are somewhat convex towards the median plane; its middle part has the appearance of a transverse slit. Its length is 7.5 cm. along its anterior wall, and 9 cm. along its posterior wall; its width gradually increases from below upwards. Its upper end surrounds the vaginal portion of the cervix uteri a short distance from the external os of the uterus, its attachment extending higher on the posterior than on the anterior wall of the uterus. To the recess behind the cervix uteri the term *posterior fornix* is applied, while the smaller recesses at the sides and in front are called the *lateral* and *anterior fornices*.

The *anterior wall* of the vagina is in relation with the base of the bladder, and with the urethra which is actually imbedded in the anterior wall of the vagina. Its *posterior wall*, which is covered with peritoneum in its upper one-fourth, is separated from the rectum by the recto-uterine pouch above, and by some loose fibro-areolar tissue in its middle two-fourths; the lower one-fourth is separated from the anal canal by a mass of muscular and fibrous tissue, named the *perineal body*. At the sides are the Levatores ani muscles (p. 603) and pelvic fascia. As the terminal portions of the ureters pass forwards and medially to reach the fundus of the bladder, they run close to the lateral fornices of the vagina, and as they enter the bladder are usually placed in front of the vagina (p. 1481). The ureter is crossed in this situation by the uterine artery.

Structure.—The vagina consists of an internal mucous lining and a muscular coat, separated by a lamina propria of connective tissue containing in its deepest layer a large number of thin-walled veins.

The *mucous membrane* is firmly fixed to the muscular coat; on its free surface there are two longitudinal ridges, one on the anterior and the other on the posterior wall of the vagina. These ridges are called the *columns of the vagina*, and from them numerous transverse ridges or rugæ extend laterally on each side. These rugæ are divided by furrows of variable depth, giving to the mucous membrane the appearance of being studded over with conical projections or papillæ; they are most numerous on the posterior wall and near the orifice of the vagina, especially before parturition. The epithelium of the mucous membrane is of the non-keratinised, stratified squamous variety. After puberty it becomes thick and is rich in glycogen. Unlike the condition in many mammals, the vaginal epithelium does not undergo very marked changes during the menstrual cycle; its glycogen increases in the post-ovulatory phase and diminishes towards the end of the cycle. The fermentative action of certain bacteria (*Döderlein's bacillus*) on the glycogen renders the fluid in the vagina acid. There are no glands in the vaginal mucous membrane, which is thus lubricated by mucus derived from the glands of the cervix of the uterus.

The *muscular coat* consists of two layers: an external longitudinal, which is by far the stronger, and an internal circular layer. The longitudinal fibres are continuous with the superficial muscular fibres of the uterus. The strongest fasciculi are those attached to the recto-vesical fascia on each side. The two layers are not distinctly separable from one another, but are connected by oblique decussating fasciculi. In addition to this, the lower end of the vagina is surrounded by a band of striped muscular fibres, termed the *Bulbo-spongiosus* (p. 609).

External to the muscular coat there is a layer of areolar tissue, containing a large plexus of blood-vessels.

Vessels and Nerves.—The *arteries* of the vagina are derived from the vaginal, uterine, internal pudendal, and middle rectal branches of the internal iliac arteries (pp. 809 to 810). The *veins* form plexuses at the sides of the vagina, and these plexuses are drained through the vaginal veins into the internal iliac veins. The *lymph vessels* are described on p. 907. The *nerves* are derived from the vaginal plexuses, and from the pelvic splanchnic nerves (p. 1222).

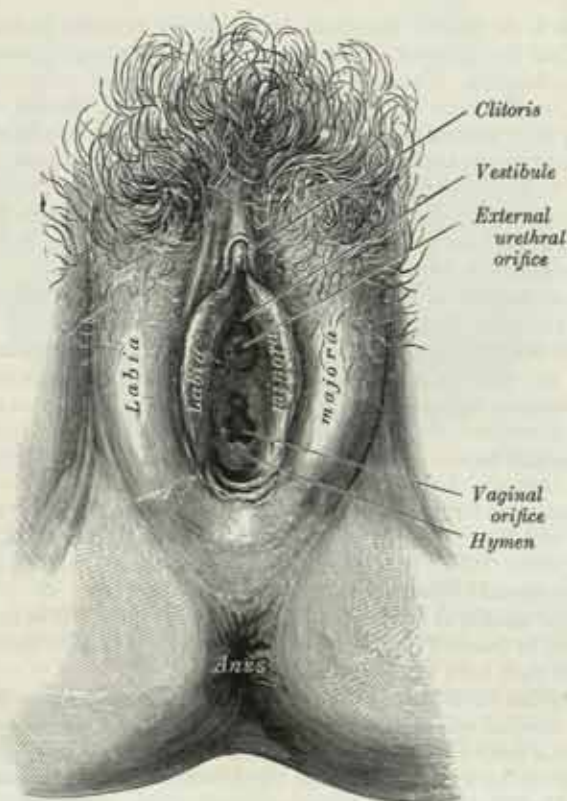
THE EXTERNAL GENITAL ORGANS OF THE FEMALE (fig. 1258)

The **external genital organs of the female** are: the mons pubis, the labia majora et minora pudendi, the clitoris, the vestibule of the vagina, the bulb of the vestibule and the greater vestibular glands. The term *pudendum* or *vulva*, as generally applied, includes all these parts.

The **mons pubis**, the rounded eminence in front of the pubic symphysis, is formed by a collection of fatty tissue beneath the skin. It becomes covered with coarse hair at the time of puberty over an area which has a horizontal upper limit. In the male the pubic hair proper has a similar upper limit and its apparent continuation upwards to the umbilicus consists of ordinary body hair.

The **labia majora** are two prominent, longitudinal, cutaneous folds which extend downwards and backwards from the mons pubis, and form the lateral

FIG. 1258.—The external genital organs of the female.
The labia have been drawn apart.



boundaries of a fissure or cleft, named the *pudendal cleft*, into which the vagina and urethra open. Each labium has two surfaces, an outer, pigmented and covered with crisp hairs; and an inner, smooth and beset with large sebaceous follicles. Between the two surfaces there is a considerable quantity of areolar tissue, fat, and a tissue resembling the dartos muscle of the scrotum, besides vessels, nerves and glands. The round ligament of the uterus ends in the fibro-fatty tissue and skin of the front part of the labium. A persistent processus vaginalis and a congenital inguinal hernia may reach the labium. The labia are thicker in front, where they form by

their meeting the *anterior commissure*. Posteriorly they are not really joined, but appear to become lost in the neighbouring integument, ending close to, and nearly parallel with, each other; together with the connecting skin between them, they form the *posterior commissure*, or posterior boundary of the pudendum. The interval between the posterior commissure and the anus, from 2.5 cm. to 3 cm. in length, constitutes the gynaecological perineum.

The **labia minora** are two small cutaneous folds, devoid of fat, situated between the labia majora, and extending from the clitoris obliquely downwards, laterally and backwards for about 4 cm. on each side of the orifice of the vagina, between which and the labia majora they end; in the virgin the posterior ends of the labia minora are usually joined across the median plane by a fold of skin, named the *frenulum of the labia*. Anteriorly, each labium minus divides into two portions; the upper division passes above the clitoris to meet its fellow of the opposite side, forming a fold which overhangs the glans clitoridis and is named the *præputium clitoridis*; the lower division passes below the clitoris and is united to its under surface, forming, with its fellow of the opposite side, the *frenulum clitoridis*. Numerous sebaceous follicles are placed on the opposed surfaces of the labia minora.

The vestibule.—The cleft between the labia minora is named the *vestibule of the vagina*: in it the vaginal and external urethral orifices are situated, and, between them, numerous small mucous glands, termed the *lesser vestibular glands*, open on the surface of the vestibule. The part of the vestibule between the vaginal orifice and the frenulum of the labia minora consists of a shallow depression named the *vestibular fossa*.

The **clitoris** is an erectile structure, homologous with the penis. It is situated below and behind the anterior commissure, partially hidden between the anterior ends of the labia minora. The *body of the clitoris* consists of two corpora cavernosa, composed of erectile tissue enclosed in a dense layer of fibrous membrane, and separated along their medial surfaces by an incomplete fibrous pectiniform septum; each corpus cavernosum is connected to the pubic and ischial rami by a *crus*. The free extremity, or *glans clitoridis*, is a small rounded tubercle, consisting of spongy erectile tissue, and highly sensitive. The clitoris is provided, like the penis, with a suspensory ligament, and with two small muscles, named the *Ischiocavernosi* (p. 610), which are inserted into the crura of the clitoris.

The **vaginal orifice** is a median slit below and behind the opening of the urethra; its size varies inversely with that of the *hymen*.

The **hymen vaginae** is a thin fold of mucous membrane situated at the orifice of the vagina; the inner surfaces of the fold are normally in contact with each other, and the vaginal orifice appears as a cleft between them. The hymen varies much in shape. When stretched, its commonest form is that of a ring, generally broadest posteriorly; sometimes it is represented by a semilunar fold, with its concave margin turned towards the pubes. Occasionally it is cribriform or its free margin forms a membranous fringe. It may be entirely absent, or may form a complete septum across the lower end of the vagina; the latter condition is known as an imperforate hymen. When the hymen has been ruptured, small rounded elevations known as the *carunculae hymenales* are found as its remains.

The **external urethral orifice** is placed about 2.5 cm. behind the glans clitoridis and immediately in front of the orifice of the vagina: it usually assumes the form of a short, sagittal cleft with slightly raised margins.

The **bulb of the vestibule** is the homologue of the bulb of the penis and adjoining part of the corpus spongiosum penis of the male, and consists of two elongated masses of erectile tissue, placed one on each side of the vaginal orifice and united to each other in front by a narrow median band termed the *commissura bulborum* (pars intermedia). Each lateral mass measures about 3 cm. in length. Their posterior ends are expanded and are in contact with the greater vestibular glands; their anterior ends are tapered and joined to one another by the commissure and to the glans of the clitoris by two slender bands of erectile tissue; their deep surfaces are in contact with the perineal membrane; superficially they are covered with the Bulbocavernosus muscle.

The **greater vestibular glands** are the homologues of the bulbo-urethral glands in the male. They consist of two small, round, or oval, bodies of a reddish-yellow colour, situated one on each side of the vaginal orifice, in contact with, and often overlapped by, the posterior end of the lateral mass of the bulb of the vestibule.

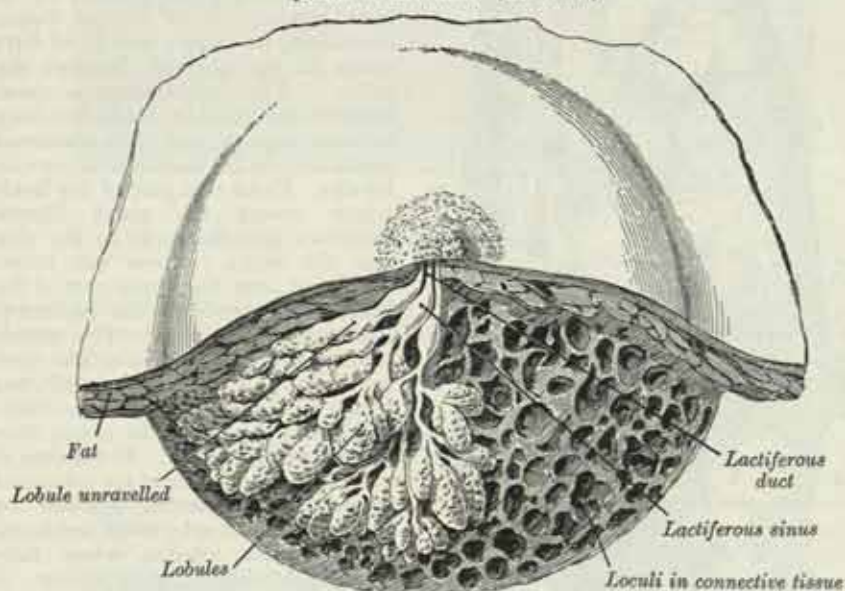
Each gland opens by means of a duct, about 2 cm. long, immediately lateral to the hymen, in the groove between its attached border and the labium minus.

Vessels and Nerves.—The arterial blood supply, venous and lymph drainage and the nerve supply of the structures comprising the external genital organs of the female are similar to those relating to the homologous structures in the male.

THE MAMMARY GLANDS (figs. 1259, 1260)

The **mammary glands** secrete the milk. They exist in the male as well as in the female, but in the former only in the rudimentary state. In the female they are two large, hemispherical eminences lying within the superficial fascia on the front and sides of the chest; each extends vertically from the second rib to the sixth rib, and, transversely, at the level of the fourth costal cartilage, from the side of the sternum to near the mid-axillary line. In weight and size they differ at different periods of life, and in different individuals. Before puberty they are small,

FIG. 1259.—A dissection of the lower half of the mammary gland during the period of lactation. (Luschka.)

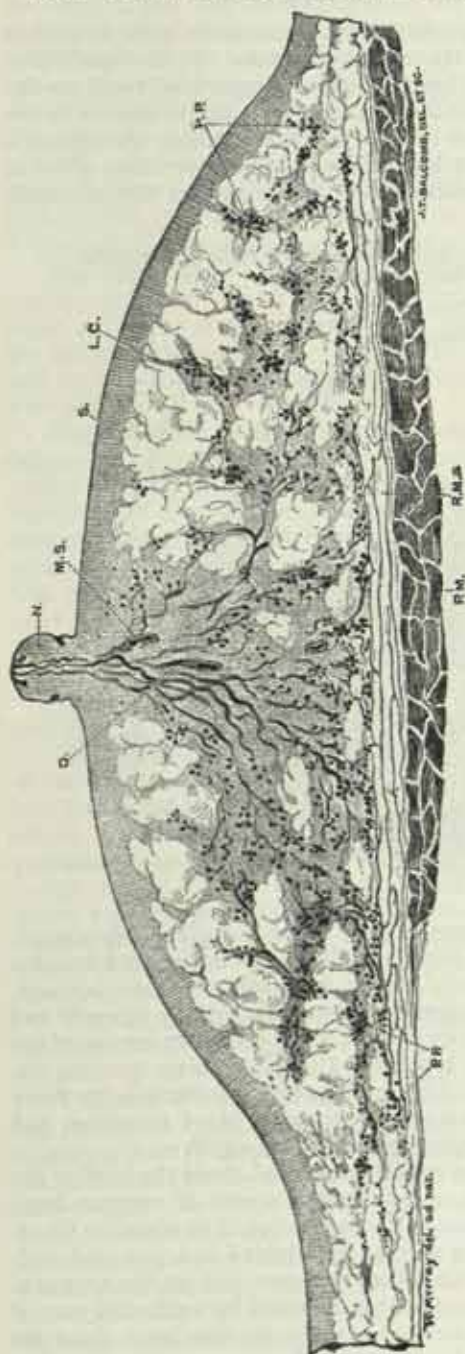


but they enlarge as the generative organs become more completely developed. They increase during pregnancy, and especially during lactation, and become atrophied in old age. The deep surface of each is flattened, or slightly concave, and irregularly circular in outline, its longest diameter being directly upwards and laterally towards the axilla, where the gland extends along the lower border of the Pectoralis major, Serratus anterior and Obliquus externus abdominis by loose areolar tissue. The subcutaneous surface of the mammary gland is convex, and presents, just below the centre, the prominence, named the *nipple*.

The **nipple** is a cylindrical or conical eminence situated about the level of the fourth intercostal space. It is capable of undergoing a sort of erection from mechanical excitement, a change mainly due to the contraction of its muscular fibres. It is of a pink or brownish hue, and its surface is wrinkled and provided with secondary papillæ; it is perforated by from fifteen to twenty orifices, the apertures of the lactiferous ducts. The base of the nipple is encircled by a coloured area of skin called the *areola*. In the virgin the areola is of a delicate rosy hue; about the second month of pregnancy it enlarges and acquires a darker tinge, and as pregnancy advances it may assume a dark brown, or even black colour. This colour diminishes as soon as lactation is over, but is never lost entirely. These changes in the colour of the areola are of importance in forming a conclusion in a case of suspected first

pregnancy. Near the base of the nipple, and upon the surface of the areola, there are numerous sebaceous glands (some of which appear to be intermediate in structure between sebaceous and sweat glands), termed the *areolar glands*, which become

FIG. 1260.—Horizontal section of the mammary gland at the level of the nipple in a multiparous female, aged forty years. (Stiles.)
(From Quain's *Anatomy*, vol. iii, part iv.)



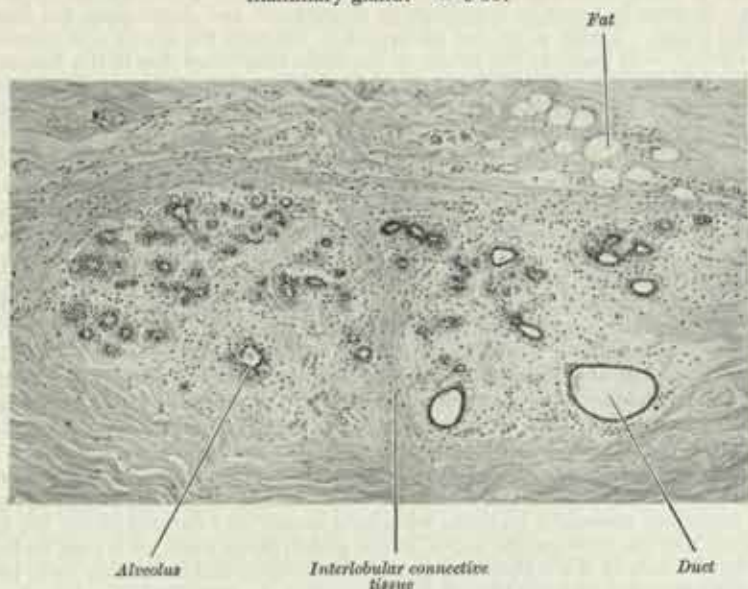
D, lactiferous duct; L.C, ligament of Cooper; M.S, lactiferous sinus; N, nipple; P.M, Pectoralis major; P.P, peripheral processes; R.M.F, retro-mammary fat; S, skin.

much enlarged during lactation and present the appearance of small tubercles beneath the skin; they secrete a peculiar fatty substance, which serves as a protection to the skin of the nipple. The nipple is traversed by the ducts of the gland, and, in addition, contains numerous vessels, intermixed with plain muscular fibres, which are principally arranged in a circular manner around the base, but a few fibres radiate from base to apex.

Structure (figs. 1259 to 1261).—The mammary gland consists (a) of gland-tissue; (b) of fibrous tissue, connecting its lobes; and (c) of fatty tissue in the intervals between the lobes. The subcutaneous tissue encloses the gland (but does not form a distinct capsule) and sends numerous septa into it to support its various lobules. From that part of the fascia which covers the gland fibrous processes pass forwards to the skin and the nipple; these are better developed over the upper part of the breast and constitute the *suspensory ligaments* (of Cooper). The gland-tissue is of a pale reddish colour, firm in texture, and forms a lobulated mass which is flattened from before backwards and thicker in the centre than at the circumference. It consists of 15 to 20 lobes, and these are composed of lobules, connected together by areolar tissue, blood-vessels and ducts. The smallest lobules, when fully developed, consist of a cluster of rounded alveoli which open into the smallest branches of the lactiferous ducts; these branches unite to form larger ducts which end in the excretory ducts or *lactiferous ducts*. The lactiferous ducts vary from fifteen to twenty in number; they converge towards the areola, beneath which they form dilatations, named *lactiferous sinuses*, which serve as reservoirs for the milk. At the base of the nipple they become contracted, and pursue a straight course to its summit, perforating it by separate orifices considerably narrower than the ducts themselves. The ducts are composed of areolar tissue containing longitudinal and transverse elastic fibres; they are lined by columnar epithelium resting on a basement-membrane. In the larger ducts the epithelium consist of two or more layers of cells and near the openings on the nipple it becomes stratified squamous in type. The epithelium of

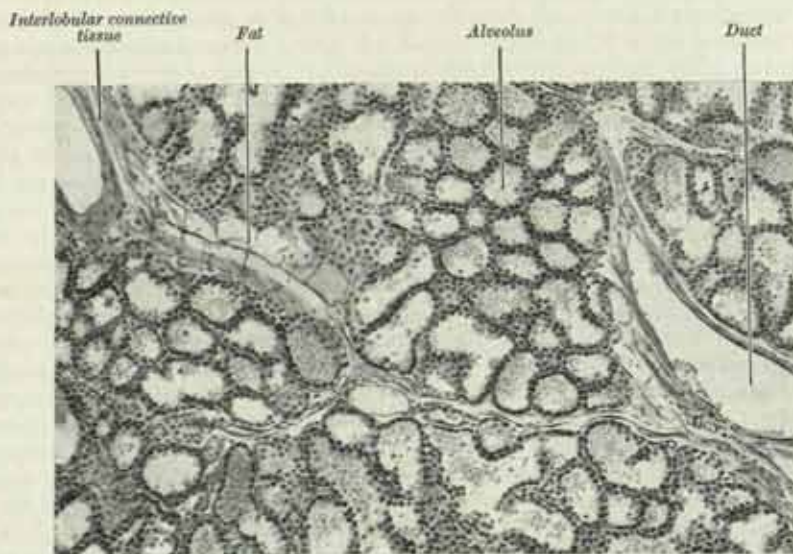
the alveoli differs according to the state of activity of the organ. In the gland of a woman who is not pregnant or suckling, the alveoli are very small and solid, being filled with a mass of granular polyhedral cells. Some consider that the 'resting breast' consists only of a duct system, without secretory alveoli. During pregnancy

FIG. 1261A.—A section through a portion of a human non-lactating mammary gland. $\times \bar{c} 60$.



the alveoli greatly develop and enlarge, and the cells undergo rapid multiplication. At the commencement of lactation, the cells in the centre of the alveolus undergo fatty degeneration, and are eliminated in the first milk, as *colostrum corpuscles*. The peripheral cells of the alveolus remain, and form a single layer of granular, short

FIG. 1261B.—A portion of an actively lactating human mammary gland. $\times \bar{c} 60$.



columnar cells, with spherical nuclei, lining the basement-membrane. When the gland is active, oil globules accumulate in the superficial parts of the cells lining the alveolus. These fat droplets are discharged into the lumen by bursting the epithelial cells. When the gland is very active, the protoplasm of the superficial parts of the

cells lining the alveolus may disintegrate also. The latter type of secretion is termed *apocrine*. When the acini are distended by the accumulation of the secretion the lining epithelium becomes flattened. Surrounding each alveolus is an incomplete layer of myo-epithelial cells which are probably contractile.*

The *fibrous tissue* invests the entire surface of the mammary gland, and sends down septa between its lobes, connecting them together.

The *fatty tissue* covers the surface of the gland, and occupies the intervals between its lobes. It usually exists in considerable abundance, and determines the form and size of the gland. There is no fat immediately beneath the areola and nipple.

Male breast.—At puberty the breast in the male resembles that in the female, both consisting of a rudimentary duct system. After puberty, the female breast, under the influence mainly of œstradiol, undergoes a slight further development, whereas normally in the male the rudimentary condition of the duct system persists.

Vessels and Nerves.—The *arteries* supplying the mammary gland are derived from the thoracic branches of the axillary artery, and from the internal thoracic and intercostal arteries. The *veins* describe an anastomotic circle round the base of the nipple, the *circulus venosus*. From this circle, branches transmit the blood to the circumference of the gland, and end in the axillary and internal thoracic veins. The *lymph vessels* are described on p. 894. The *nerves* are derived from the anterior and lateral cutaneous branches of the fourth, fifth, and sixth thoracic nerves. These nerves convey sympathetic fibres to the breast, but its secretory activities are largely under the control of hormones derived from the ovary and the hypophysis cerebri.

Applied Anatomy.—The ducts descending from the nipple radiate through the gland, and when an incision is made into the breast the scalpel should be directed radially, from the centre to the periphery, so that it may not pass across the ducts. A milk duct may become obstructed and distended, forming a cyst known as a galactocoele. Abscess frequently occurs about the mammary gland, more often in women who are lactating, especially in those who have cracks and fissures about the nipple. The abscess may be between the septa, in the gland-tissue itself, or it may lie beneath the skin by the side of the nipple and superficial to the gland, or it may form beneath the gland, between it and the deep fascia.

Supernumerary mammary glands (polymastia) or nipples (polythelia) may be present in the male or female, and usually occur somewhere along the line of the embryonic milk-ridge (p. 124) which extends from the axilla to the inguinal region. Occasionally the male breast may undergo hypertrophy after puberty (gynæcomastia).

* Richardson, K. C., *Proc. Roy. Soc. B.*, 136, 30, 1949.

THE DUCTLESS GLANDS

The *ductless glands*, or *endocrine organs*, produce secretions called hormones, which pass *directly* from the glandular cells into the bloodstream and are thus carried to all parts of the body, where they influence the functional activities of the cells in specific ways, the influence being either excitatory or inhibitory in nature. The action of a hormone may only be manifest on one particular tissue or organ (receptor organ), and, although each ductless gland produces a hormone or hormones with specific functions, it is to be noted that there is a harmonious and integrated inter-relationship between the activities of the several ductless glands.

Although organs like the thyroid gland, parathyroid glands, suprarenals, hypophysis cerebri and pineal body form separate distinct ductless glands, in the case of some other organs only some of the constituent cells are of the nature of endocrine organs producing internal secretions, for example, the cell-islets of the pancreas, the interstitial cells of the testis, and the interstitial cells and cells in the ovarian follicles and corpora lutea of the ovary. These, as well as the hypophysis and pineal body have been described in preceding Sections. For convenience, the spleen, thymus, paraganglia, carotid bodies and coccygeal body will be included in this Section, although the evidence that they function as endocrine organs is not conclusive.

THE THYROID GLAND (fig. 1262)

The **thyroid gland** is a highly vascular organ, situated at the front and sides of the lower part of the neck, opposite the fifth, sixth and seventh cervical and the first thoracic vertebræ. It is ensheathed by the pretracheal layer of the deep cervical fascia (fig. 566), and consists of right and left lobes connected across the median plane by a narrow portion, termed the *isthmus*. Its weight is somewhat variable, but is usually about 30 gm. It is slightly heavier in the female, in whom it becomes enlarged during menstruation and pregnancy.

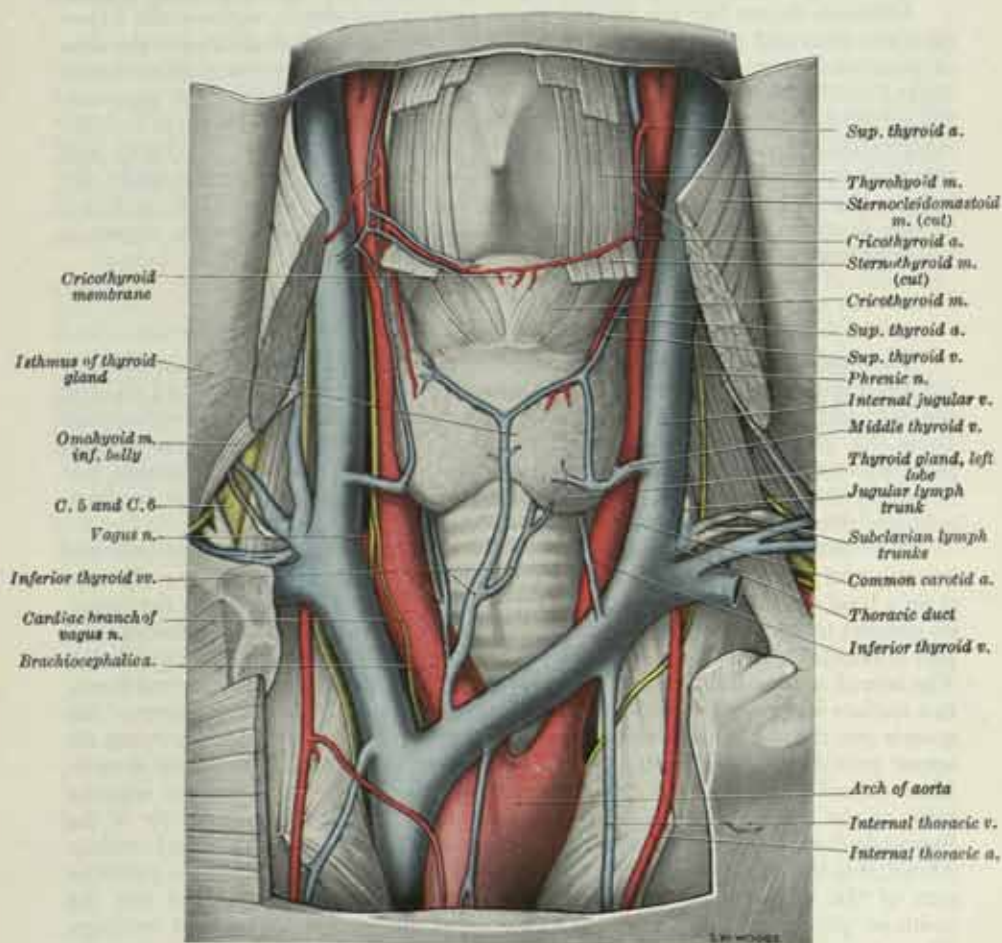
The *lobes* are conical in shape, the apex of each being directed upwards and laterally and reaching the level of the oblique line of the thyroid cartilage; the base is on a level with the fourth or fifth tracheal ring. Each lobe is about 5 cm. long; its greatest width is about 3 cm., and its thickness about 2 cm. The posteromedial part of each lobe is attached to the side of the cricoid cartilage by a ligamentous band. The *lateral*, or *superficial*, *surface* is convex. Outside the sheath of pretracheal fascia, this surface is closely covered with the Sternothyroid and it is the insertion of this muscle into the oblique line on the lamina of the thyroid cartilage which prevents the upper part of the lobe from extending forwards on to the Thyrohyoid muscle. More superficially, this surface is covered with the Sternohyoid and the superior belly of the Omohyoid muscle, overlapped below by the anterior border of the Sternocleidomastoid. The *medial surface* is moulded over the larynx and trachea. Above, it is in contact with the Inferior constrictor of the pharynx and the posterior part of the Cricothyroid muscle, which intervene between the gland and the posterior part of the lamina of the thyroid and the side of the cricoid cartilage. The external laryngeal nerve passes deep to this part of the gland on its way to the Cricothyroid muscle. Below, it is related to the side of the trachea in front, and to the recurrent laryngeal nerve and (particularly on the left side) to the œsophagus behind. The *posterolateral surface* is related to the carotid sheath and overlaps the common carotid artery. The *anterior border*, which is closely related to the anterior branch of the superior thyroid artery, is thin and inclines obliquely from above downwards and medially. The *posterior border*, which is blunt and rounded, intervenes between the posterior and the medial surfaces and is closely related below to the inferior thyroid artery and an anastomosing branch which connects that vessel to the posterior branch of the superior thyroid artery. In addition the parathyroid glands are usually related to this border. The lower end of the posterior border of the left lobe is closely related to the thoracic duct.

The *isthmus* connects together the lower parts of the two lobes; it measures about 1.25 cm. transversely, and the same vertically, and usually covers the second and third rings of the trachea, though it is often placed at a higher, and occasion-

ally at a lower, level. Its situation and size present, however, many variations. Anteriorly, it is separated by the pretracheal fascia from the Sternothyroid muscles. More superficially it is covered by the Sternohyoid muscles, the anterior jugular veins, the fascia and the skin. An anastomotic branch uniting the two superior thyroid arteries runs along its upper border; at its lower border the inferior thyroid veins leave the gland. Sometimes the isthmus is altogether wanting.

A third lobe, of conical shape, called the *pyramidal lobe*, frequently extends from the upper part of the isthmus, or from the adjacent portion of either lobe, but more

FIG. 1262.—A dissection of the lower part of the front of the neck and of the superior mediastinum.



The manubrium sterni and the sternal ends of the clavicles and first costal cartilages have been removed and the pleural sac and lung have been retracted on each side.

commonly the left, to the hyoid bone. It is occasionally quite detached, or may be divided into two or more parts.

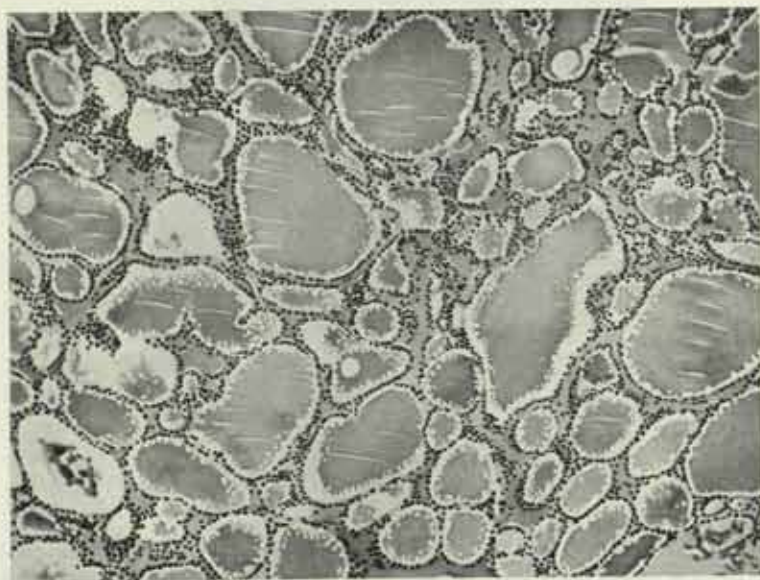
A fibrous or muscular band is sometimes attached, above, to the body of the hyoid bone, and below, to the isthmus of the gland, or its pyramidal lobe; when muscular, it is termed the *Levator glandulae thyroideae*.

Small detached portions of thyroid tissue are sometimes found in the vicinity of the lobes or above the isthmus; they are called *accessory thyroid glands*. Remnants of the thyroglossal duct (p. 184) may persist between the isthmus and the foramen cæcum of the tongue and may give rise to accessory nodules of thyroid tissue.

Structure.—The thyroid gland is closely invested by a thin capsule of connective tissue and it is divided into masses of irregular form and size. The gland is of a

brownish-red colour and is made up of a number of closed follicles, just visible to the naked eye, containing a yellow, glairy fluid, and separated from each other by connective tissue. The follicles are arranged in groups or gland-units. Each follicle is lined with a single layer of cubical epithelium (fig. 1263). The shape of the cells varies with the state of activity of the gland, being flattened if the follicles are filled with colloid material and low-columnar if the follicles contain little colloid. There is no basement-membrane, so that the epithelial cells are in direct contact with the connective tissue reticulum and blood vessels. The follicles are of various sizes, and contain a viscid, homogeneous, semi-fluid, slightly yellowish, colloid material. The colloid contains an iodine compound, *thyroxin*,* which is the hormone produced by the thyroid, and which is firmly bound to the protein thyroglobulin. The colloid is readily stained by eosin. The thyroxin passes out between the cubical cells and is absorbed into the blood. By the use of the radioactive isotope of iodine it has been shown that most of ingested iodine is rapidly taken up by the thyroid gland. By the method of autoradiography, which involves placing histological sections of the gland (containing radioactive iodine) on a photographic plate, the iodine is observed to be present at first in the cells lining the follicles and then rapidly passed from them into the colloid. Thyroxin controls the basal metabolic rate of tissues; over-secretion

FIG. 1263.—Section of human thyroid gland. $\times 90$. The colloid has partly shrunk away from the epithelial walls of the follicles.



causes the disease called exophthalmic goitre; insufficient secretion in the adult produces the condition of myxœdema, and in the child thyroid cretinism.

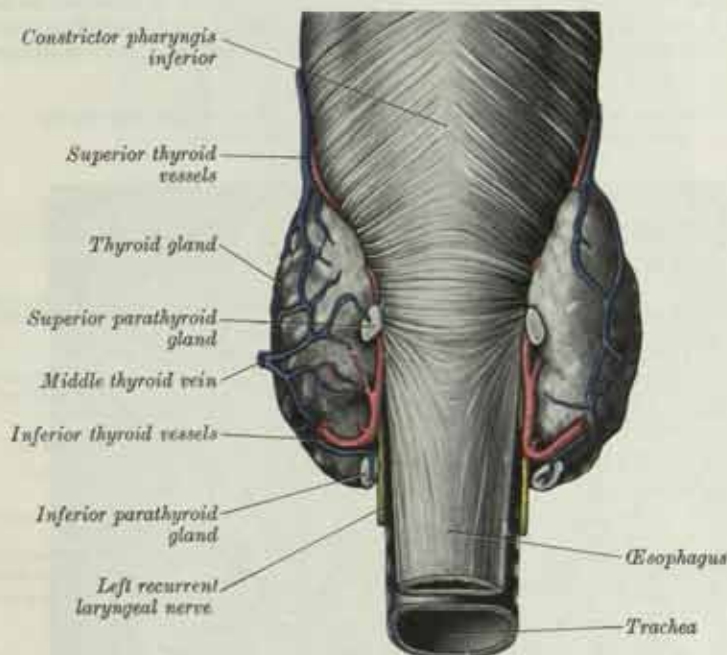
Vessels and Nerves.—The *arteries* supplying the thyroid gland are the superior (p. 739) and inferior thyroid arteries (p. 772); sometimes there is an additional branch (a. thyroidea ima) from the brachiocephalic artery or the arch of the aorta, which ascends upon the front of the trachea. The arteries are remarkable for their large size and frequent anastomoses. The *veins* form a plexus on the surface of the gland and on the front of the trachea; from this plexus the superior, middle and inferior thyroid veins arise; the superior and middle end in the internal jugular vein, the inferior in the left brachiocephalic vein. The capillary blood-vessels form a dense plexus in the connective tissue around the follicles, between the epithelium of the follicles and the endothelium of the lymph vessels which surround a greater or smaller part of the circumference of the follicle. The *lymph vessels* run in the interlobular connective tissue, not uncommonly surrounding the arteries which they accompany, and communicate with a network in the capsule of the gland; they may contain colloid material. They end in the thoracic duct and the right lymphatic duct. The *nerves* are derived from the superior, middle and inferior cervical ganglia of the sympathetic.

* Other thyroid hormones have recently been discovered, the chief of which is triiodothyronine.

Applied Anatomy.—Any enlargement of the thyroid gland is called a goitre. Pressure may be exerted by the enlarged gland on any of the structures related to it. Symptoms are most commonly referable to pressure on the trachea or recurrent laryngeal nerve.

Partial extirpation of the thyroid may be required in cases of parenchymatous goitre, in the diffuse form of adenomatous disease and in exophthalmic goitre. Enough of the gland must be taken away to relieve the symptoms, but, except in malignant disease, the whole gland must never be removed, as such a procedure is followed by the development of myxœdema. In dealing with the inferior thyroid artery, the position of the recurrent laryngeal nerve (p. 772) must be borne in mind, lest it should be ligatured or divided. Temporary aphonia not uncommonly follows

FIG. 1264.—A dissection of the lower part of the pharynx and the upper part of the œsophagus from behind, to show the position of the parathyroid glands.



from bruising of the nerve, and if nothing more serious has occurred soon passes off.

In partial removal of the thyroid gland it is customary to leave behind the posterior part of each lobe, as, if this portion is taken away, there is great risk of coincident removal of the parathyroid glands.

THE PARATHYROID GLANDS

The **parathyroid glands** (fig. 1264) are small, yellowish-brown, ovoid or lentiform bodies, which usually lie between the posterior borders of the lobes of the thyroid gland and its capsule. They vary in size, but commonly measure about 6 mm. in length, 3 mm. to 4 mm. in width and 1 mm. to 2 mm. in thickness. Usually they are four in number, two on each side, and are called, from their positions, the superior and inferior parathyroids. The anastomotic artery connecting the superior to the inferior thyroid artery runs along the posterior border of the lobe of the thyroid gland and, as it usually passes very close to the parathyroids, it forms a good guide to them.

The *superior parathyroid gland* is more constant in position than the inferior parathyroid, and is usually situated at the level of the middle of the posterior border of the lobe of the thyroid gland, though it may lie at a higher level. The *inferior parathyroid gland* may lie in various positions,* e.g. (1) within the fascial sheath of the thyroid gland, below the inferior thyroid artery and near the lower pole of

* A. J. Walton, *Brit. J. Surgery*, 1931, 19, 285.

the lobe of the thyroid; (2) behind and outside the fascial sheath of the thyroid gland, immediately above the inferior thyroid artery; or (3) within the substance of the lobe of the thyroid gland near the lower end of its posterior border. These variable positions are important surgically, since a tumour of the inferior parathyroid which occupied position (1) tends to sink downwards along the inferior thyroid veins, in front of the trachea into the superior mediastinum of the thorax, whereas if the gland occupied position (2) the tumour tends to pass downwards and backwards, behind the œsophagus into the posterior mediastinum.

The parathyroid glands are developed from the entoderm of the pharyngeal pouches (p. 185), the inferior parathyroids from the third pouch and therefore

FIG. 1265.—A section of a human parathyroid gland, showing principal cells arranged in columns. $\times 65$.



sometimes referred to as parathyroids III, and the superior parathyroids from the fourth pouch and therefore called parathyroids IV. The inferior parathyroid is closely connected in the early stages of its development with the diverticulum from the third pouch which forms the thymus and it is drawn down with the thymus in the caudal migration of the latter. Normally the inferior parathyroid migrates only as far as the lower pole of the lobe of the thyroid gland, but it may descend, with the thymus into the thorax, or it may not descend at all and remain above its normal level, near the bifurcation of the common carotid artery.

The parathyroid glands vary in number; there may be many minute islands of parathyroid tissue scattered in the connective tissue and fat in the region of the usual position of the glands, or there may only be three glands.

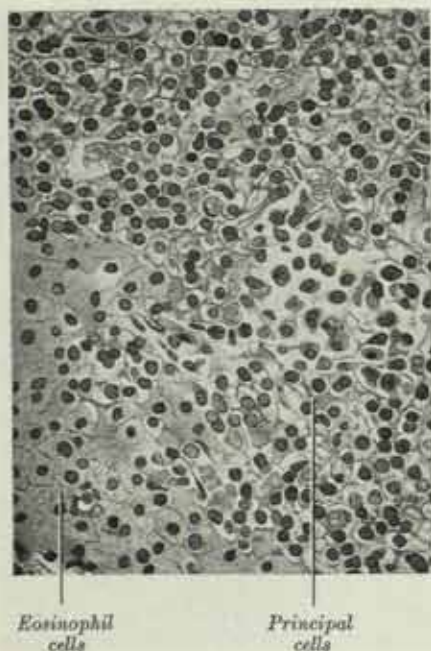
Vessels and Nerves.—The parathyroid glands receive a very rich *blood-supply* from the inferior thyroid arteries or from the anastomoses between the superior and inferior thyroid arteries. Their *lymph* vessels are numerous, and are associated with those of the thyroid and thymus glands. Their *nerve-supply* is derived from the sympathetic, either directly from the superior or middle cervical ganglia, or indirectly through a plexus in the fascia on the posterior surface of the lobes of the thyroid gland.

Structure (figs. 1265, 1266).—Each parathyroid has a thin connective tissue capsule, from which septa pass into the gland but do not subdivide it into distinct lobules. In the child, the gland consists of wide, irregular anastomosing columns or cords of cells, the *principal cells* (or chief cells), of which there are three types, named according to

the depth of staining of their homogeneous, non-granular cytoplasm—(a) *dark principal cells*, (b) *light principal cells* and (c) *clear principal cells* in which the cytoplasm is not easily stained. Between the columns there is a rich network of large capillaries (sinusoids). The parathyroid hormone is elaborated by the principal cells. At about the age of 5 to 7 years, other cells appear—the *oxyphil* (or *eosinophil*) cells, the function of which is not known. They are larger than the principal cells and contain more cytoplasm, which is granular and stains deeply with eosin. The nuclei are smaller and more darkly staining. They are believed to be derived from the principal cells, since intermediate types of cells are also present. The principal cells may, in places, form follicles containing colloid material, and, as age advances, much fat may be deposited in the glands.

The parathyroid hormone is concerned with the metabolism of calcium and phosphorus in the body. If all the parathyroids are removed, the muscles, due to a

FIG. 1266.—Section of human parathyroid gland to show principal and eosinophil cells. $\times 250$.



reduction of calcium ions in the blood, undergo convulsive spasms (tetany) and, as the respiratory muscles (including the laryngeal muscles) are involved, death ensues. Excess of parathyroid secretion, such as occurs in tumours of the glands, results in removal of calcium ions from the bones, so that they become soft, a condition known as generalised osteitis fibrosa. The calcium ions pass from the bones into the blood (hypercalcaemia) and are excreted in the urine and may cause calcification in the renal tubules with resultant death from kidney disease. How the parathyroid hormone acts is uncertain; it may stimulate osteoclastic activity in the bones, or upset the reciprocal relations of calcium and phosphorus ions in the blood.

THE CHROMAFFIN SYSTEM

The **chromaffin system** comprises numerous masses of cells which, like those in the medulla of the suprarenal gland, contain in their cytoplasm granules that stain yellowish-brown with chromic acid salts; the cells are thus known as chromaffin cells or phaeochromocytes. The cells are derived from the sympatho-chromaffin tissue of the neural crests (p. 145), a tissue from which sympathetic neurones are also derived, and the masses are found in intimate relationship to parts of the sympathetic nervous system. Chromaffin cells secrete noradrenalin and adrenalin (see p. 1538) and they are innervated by preganglionic fibres of the sympathetic, so that the cells themselves are analogous to postganglionic sympathetic neurones.

In addition to the medulla of the suprarenal gland, the chromaffin tissue includes (a) the paraganglia, (b) the para-aortic bodies, and (c) small masses of chromaffin cells scattered irregularly and variably among the sympathetic plexuses and in relation to various organs (heart, liver, kidney, ureter, prostate, epididymis, ovary, etc.).

The **paraganglia** are spherical masses of chromaffin cells, about 2 mm. in diameter; each paraganglion lies inside, or immediately outside, or embedded in the capsule of a ganglion of the sympathetic trunk. In the adult they are generally represented by microscopic remnants only.

The **para-aortic bodies** progressively develop during foetal life and attain their maximum size in the first three years of postnatal life, when they take the form of two elongated, brownish bodies, about 1 cm. long, which lie on either side of the abdominal aorta in the region of origin of the inferior mesenteric artery. They are usually united across the front of the aorta by a horizontal mass, which lies immediately above the origin of the inferior mesenteric artery, so as to form collectively an inverted horse-shoe, or H-shaped arrangement. They are intimately related to the intermesenteric nerves and the superior hypogastric plexus. They undergo progressive atrophy and by the age of 14 years are completely disintegrated.* When well developed, they consist of masses of polygonal chromaffin cells embedded in a wide-meshed capillary plexus. The chromaffin cells of the para-aortic bodies secrete noradrenalin (see p. 1538).

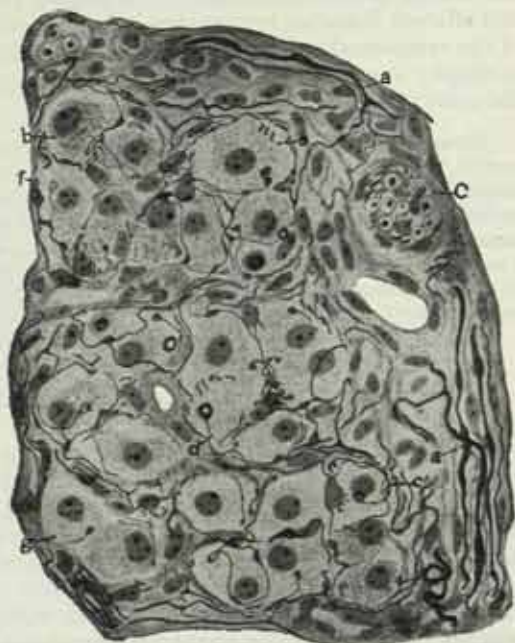
Other small chromaffin bodies are found in the foetus in all parts of the abdominal and pelvic prevertebral sympathetic plexuses, but they reach their maximum size between the fifth and eighth months of foetal life,* and in the adult they are present as discrete structures only in the vicinity of the coeliac and superior mesenteric arteries, while only microscopic collections of chromaffin cells persist in association with the lower parts of the intermesenteric nerves.†

THE CAROTID BODIES

The **carotid bodies**, two in number, are reddish-brown, ellipsoidal structures, situated one on each side of the neck, in close relation to the carotid sinus (p. 736). Each is about 5 mm. in height and 2.5 mm. to 4 mm. in width and varies slightly in position; it may lie deep to the bifurcation of the common carotid artery, or completely or partially wedged in between the commencements of the internal and external carotid arteries, and is attached to, and sometimes partially embedded in, the outer fibrous coat of these arteries. Occasionally the organ is in the form of a number of separate nodules.

Structure.—The carotid body is invested by a fibrous capsule from which septa pass into the organ and divide it into lobules. Each lobule consists of masses of large, polyhedral, 'epithelioid' cells, interspersed among which are networks of sinusoidal blood vessels derived from the vessels in the septa. Each 'epithelioid' cell

FIG. 1267.—A section of the carotid body, showing nerve-fibres distributed to the cells. (de Castro.) (From Sharpey-Schafer's *Essentials of Histology*.)



a, Myelinated fibre dividing into two branches; b, cell closely surrounded by nerve-fibrils; c, section of a small nerve, composed of several myelinated fibres; d, a nerve-fibril apparently ending within the cytoplasm of a cell; e, a nerve-fibril ending between the cells.

* R. E. Coupland, *J. Anat., Lond.*, 1954, 88, 455.

† R. E. Coupland, *J. Anat., Lond.*, 1952, 86, 357.

contains a large, pale-staining nucleus and pale-staining, finely granular cytoplasm, and the cells are closely applied to the endothelium lining the sinuses. The 'epithelioid' cells are not chromaffin cells, but a few chromaffin cells have been described as scattered here and there in the carotid body. Abundant nerve-fibres permeate among the 'epithelioid' cells and very numerous sensory nerve-endings are present in relation to the 'epithelioid' cells and to the sinusoids (fig. 1267). The nerves are derived mainly from the carotid branch of the glossopharyngeal nerve (p. 1128), and also from the superior cervical ganglion of the sympathetic and the inferior ganglion of the vagus. The carotid body is developed from the mesenchyme of the third pharyngeal arch,* first appearing as a condensation of the mesenchyme around the third pharyngeal arch artery, and its nerve-supply is mainly from the nerve of that arch (glossopharyngeal). Functionally, the carotid body acts as a chemoreceptor, responding to changes in the chemical composition of the blood, a fall in the oxygen content or an increase in carbon dioxide content of the blood circulating through the organ initiating chemoreceptor reflexes through the glossopharyngeal and vagus nerves and stimulating respiration.

Other small bodies, with a structure similar to that of the carotid bodies, are found in relation to the arteries of the fourth and sixth pharyngeal arches; they lie close to the arch of the aorta, the ductus arteriosus and the right subclavian arteries and are supplied by branches of the vagus nerves. They are believed to function as chemoreceptors.

The jugular glomus or tympanic body.†—This is a small ovoid body, about 0.5 mm. long and 0.25 mm. broad, which lies in the adventitia of the upper part of the superior bulb of the internal jugular vein. Its structure is similar to that of the carotid body. It may consist of two or more masses which may be related to the tympanic branch of the glossopharyngeal nerve or the auricular branch of the vagus, as these nerves lie in their canals in the petrous part of the temporal bone. Tumours of these bodies may occur and cause symptoms attributable to involvement of the neighbouring cranial nerves and the middle ear.

THE COCCYGEAL BODY

The **coccygeal body** is placed in front of, or immediately below, the tip of the coccyx, at the termination of the median sacral vessels, which supply afferent and efferent branches to the organ, and it is closely related to the ganglion impar of the sympathetic trunks. It is about 2.5 mm. in diameter and is irregularly oval in shape; several smaller nodules with similar structure are found around or near the main mass.

Structure.—The coccygeal body consists of irregular masses of spherical or polyhedral 'epithelioid' cells, the cells of each mass being grouped around a dilated, sinusoidal capillary vessel. Each cell contains a large, round or oval nucleus, the cytoplasm surrounding which is clear and is not stained by chromic salts, so that the organ does not belong to the chromaffin system. The sinusoidal vessels form part of a complex system of arteriovenous anastomoses, and the 'epithelioid' cells appear to be modified muscle cells of the walls of the vessels. The functional significance of the organ is not known.

THE SUPRARENAL GLANDS (figs. 1205, 1268, 1269)

The **suprarenal glands** (or **adrenal glands**) are two small, flattened bodies of a yellowish colour, situated, one on each side of the median plane, at the posterior part of the abdomen, behind the peritoneum, and immediately above and in front of the upper end of the kidney. They are surrounded by areolar tissue containing a considerable amount of fat. They are enclosed, together with the kidneys, in the renal fascia, but are separated from the kidneys by a little fibro-areolar tissue. Each gland consists of an outer cortical portion, which is rich in lipoids and contains no chromaffin tissue, and an inner medullary portion, which stains deeply with chromic salts. In man it is not uncommon to find small masses of tissue, identical with the suprarenal cortex, in the neighbourhood of the gland or in other situations. They are termed 'cortical bodies'. Ontogenetically, phylogenetically, structurally, and functionally, the cortex and the medulla of the suprarenal gland are distinct from each other, but together they constitute a single entity anatomically.

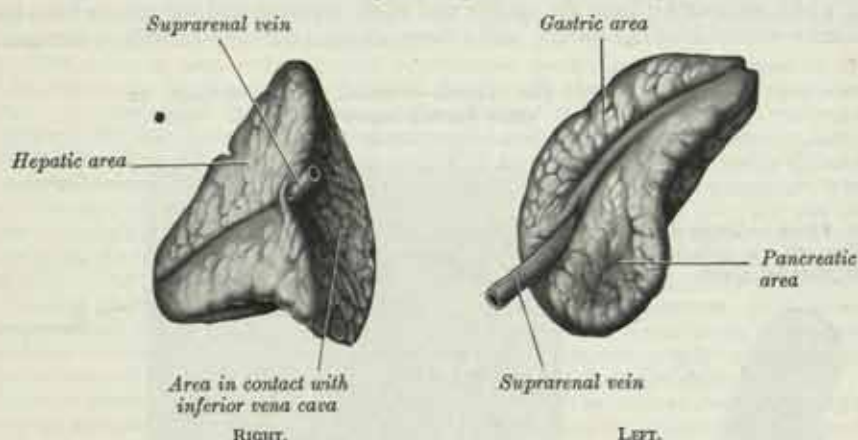
The right gland is somewhat pyramidal in shape, bearing a resemblance to a

* J. D. Boyd, *Contrib. to Embryol.*, 1937, 26, 1.

† S. R. Guild, *Anat. Rec.*, 1941, 79, p. 28 (Suppl.).

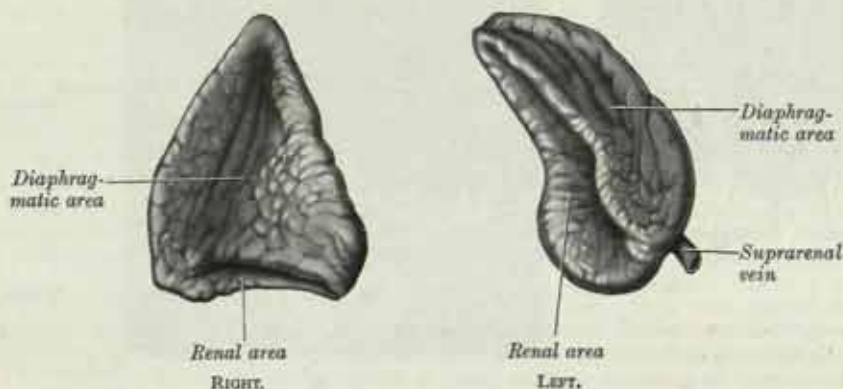
cocked hat; the left is semilunar, and is usually larger and extends to a higher level than the right. Each gland measures from 30 mm. to 50 mm. in height; about 30 mm. in breadth, and from 4 mm. to 6 mm. in thickness. The average weight of each is from 3 gm. to 4 gm.

FIG. 1268.—The suprarenal glands. Anterior aspect.



Relations.—The *right suprarenal gland* (fig. 1205) is situated behind the inferior vena cava and the right lobe of the liver, and in front of the Diaphragm and upper end of the right kidney. It is roughly triangular in shape; the base, usually directed downwards, is in contact with the medial and anterior surfaces of the upper end of the right kidney. Frequently the base is related to the upper part of the medial border of the right kidney and not to its upper pole. The *anterior surface* looks forwards and laterally, and has two areas: a medial, narrow and non-peritoneal,

FIG. 1269.—The suprarenal glands. Posterior aspect.



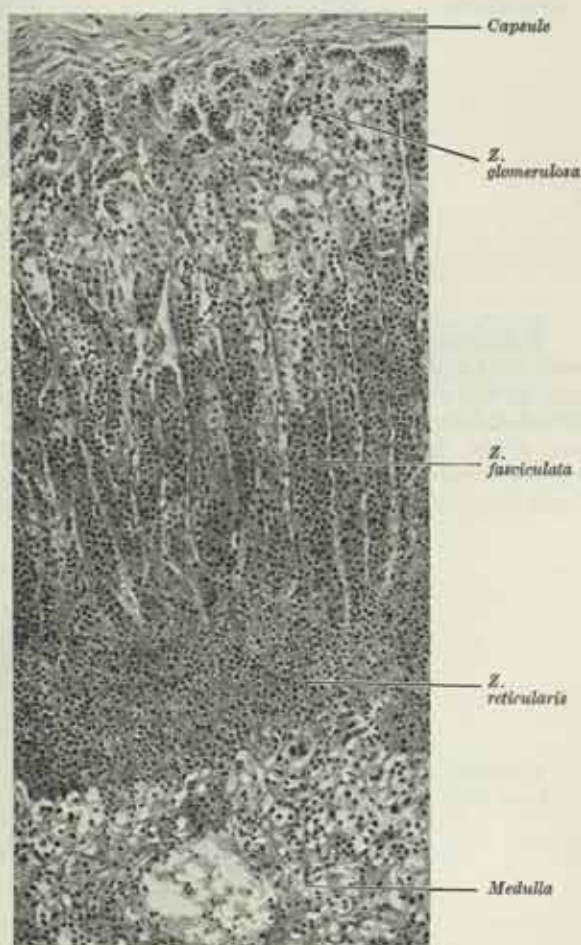
which lies behind the inferior vena cava; and a lateral, somewhat triangular, in contact with the liver. The upper part of the latter surface is devoid of peritoneum, and is in relation with the lower and medial angle of the bare area of the liver, while its inferior portion may be covered by peritoneum, reflected on to it from the inferior layer of the coronary ligament; occasionally the duodenum overlaps the inferior portion. A little below the apex, and near the anterior border of the gland, there is a short furrow termed the hilus, from which the right suprarenal vein emerges to join the inferior vena cava. Its *posterior surface* is divided into upper and lower parts by a curved ridge; the upper, slightly convex, rests upon the Diaphragm; the lower, concave, is in contact with the upper end and the adjacent part of the anterior surface of the right kidney. The thin *medial border* of the gland is related to the right celiac ganglion, which lies medial to its lower part, and to the right

(inferior) phrenic artery, as the vessel courses upwards and laterally on the right crus of the Diaphragm.

The *left suprarenal gland* (fig. 1205) is crescentic in shape, its concavity being adapted to the medial border of the upper part of the left kidney. Its medial border is convex, its lateral concave; its upper end is narrow, its lower rounded. Its *anterior surface* has two areas: an upper, covered with the peritoneum of the lesser sac, which separates it from the cardiac end of the stomach and sometimes from the posterior extremity of the spleen; and a lower, which is not covered with peritoneum,

FIG. 1270B.—Vertical section through an adult human suprarenal gland. $\times 180$.

FIG. 1270A.—Vertical section through a whole adult suprarenal gland. $\times 4$.



but is in contact with the pancreas and splenic artery. The hilus, which is directed downwards and forwards, is placed near the lower part of the anterior surface. From it the left suprarenal vein emerges to join the left renal vein. Its *posterior surface* is divided into two areas by a ridge; the lateral area rests on the kidney, the medial and smaller, on the left crus of the Diaphragm. The convex *medial border* is related to the left celiac ganglion, which lies medial to its lower part, and to the left phrenic and left gastric arteries, as they run upwards on the left crus of the Diaphragm.

Small *accessory suprarenal glands*, which may consist of cortical tissue only, are often found in the areolar tissue round the suprarenal glands; they are sometimes present in the spermatic cord and epididymis, and in the broad ligament of the uterus.

Structure (fig. 1270 A and B).—If a suprarenal gland is cut across, it is seen with the naked eye to consist of an outer part, called the cortex, which is yellow in colour and forms the main mass of the gland, and a thin inner part, called the *medulla*, which forms only about one-tenth of the whole gland and is dark red or pearly grey in colour depending on whether it contains blood or not. The medulla is completely enclosed by the cortex, except at the hilus where the suprarenal vein emerges from the gland. The gland is invested by a thick, collagenous capsule from which trabeculae pass for varying depths into the cortex; the capsule contains a rich plexus of arteries from which branches pass into the gland.

The *cortex* is seen on histological examination to consist of three zones of cells. The outer zone lies immediately beneath the capsule and is called the *zona glomerulosa*; it consists of short columnar cells arranged in rounded groups or curved columns, the cells having deeply staining nuclei and a scanty basophilic cytoplasm in which a few lipid droplets may be present. The next zone is broader and is called the *zona fasciculata*; it consists of large polyhedral cells with basophilic cytoplasm which are arranged in straight columns; the cells contain numerous lipid droplets and large amounts of phospholipins, fats, fatty acids and cholesterol. The innermost zone of the cortex is called the *zona reticularis*; it consists of branching and anastomosing columns of cells. The cells contain few lipid droplets; in some of the cells there are yellow or brownish granules and some of the cells show evidence of degeneration. It is believed by some that the cells in the *zona glomerulosa*, particularly those in its deeper part, undergo continuous proliferation, the daughter cells migrating deeply to form the *zona fasciculata* and subsequently moving more deeply still to form the *zona reticularis*; in the latter zone the cells degenerate and are absorbed. The cells of the cortex produce various hormones and, particularly those of the *zona fasciculata*, are very rich in ascorbic acid (vitamin C). The cells of the *zona glomerulosa* appear to produce hormones of the deoxycorticosterone type that maintain electrolyte and water balance in the body tissues; the cells in the *zona fasciculata* produce hormones of the corticosterone type that maintain carbohydrate balance; and the cells of the *zona reticularis* produce hormones of the steroid type, namely sex hormones (progesterone, oestrogenic hormones and androgenic hormones). The cortex is essential for life; complete removal results in death unless cortisone is given. In some mammals the cortex plays a large part in controlling the cyclical phenomena of the oestrus cycle, during which the cortex undergoes cycles of hypertrophy and regression. Between the cells of the cortex lie sinusoids, into which most of the branches of the capsular arterial plexus open, though some arteries pass straight through the cortex to the medullary sinusoids. The cortical sinusoids also convey blood to the medullary sinusoids. The endothelial cells of the sinusoids are phagocytic and belong to the macrophage (reticulo-endothelial) system. The cortex first develops early in the second month of intra-uterine life as a proliferation of the mesodermal coelomic epithelium on the posterior abdominal wall, between the root of the dorsal mesentery and the gonad. The cells become large and eosinophilic and form the *fœtal cortex* (or *boundary zone*) of the suprarenal. Later in the same month, another proliferation of the coelomic mesothelium produces smaller basophilic cells which form a thin layer superficial to the fœtal cortex; these cells form the *definitive* (or adult) *cortex* of the gland. At birth, the relatively large size of the suprarenal is due to the very thick layer of fœtal cortex, the definitive cortex forming only a thin zone. About the time of birth the fœtal cortex begins to undergo regression and it has largely disappeared after a few weeks. Too rapid involution of this cortex may cause fatal hæmorrhage in the suprarenal glands. This transient fœtal cortex is found only in Anthropoids. There is no conclusive evidence that it produces androgenic hormones. It is very poorly developed in anencephalic fœtuses. It does not represent the X-zone (or androgenic zone) found, for instance, in the young mouse as a zone surrounding the medulla.*

The *medulla* of the suprarenal gland is composed of groups and columns of chromaffin cells (or phæochromocytes) with wide venous sinusoids permeating between them. Small groups of nerve-cells, or even single nerve-cells, are found here and there in the medulla. The chromaffin cells produce adrenalin and nor-adrenalin, which pass from the cells directly into the sinusoids. The sinusoids open into the suprarenal vein at the hilus of the gland. Normally little adrenalin and noradrenalin are secreted, but under emergency conditions of fear, anger, stress, etc., the secretion is considerably increased and produces cardiac acceleration, vaso-constriction, raised blood-pressure, etc., by reinforcing the activity of the sympathetic nervous system. Unlike the cortex, the medulla of the suprarenal is not essential for life and its removal has no marked effect. The chromaffin cells of the medulla develop and migrate from the neural crests (sympatho-chromaffin tissue, p. 145). The chromaffin reaction (brown staining of the granules in the cells by potassium bichromate due to oxidation of the adrenalin and noradrenalin in the granules) is shown

* I. C. Jones, *Brit. Med. Bull.*, 1955, **11**, 156.

first in the fifth month of foetal life, but adrenalin is present as early as the third month.*

Functional relationship between the cortex and medulla of the suprarenal gland.—It is only in mammals that the chromaffin tissue of the suprarenal becomes almost completely enclosed by cortical tissue. In cartilaginous fish (e.g. the dogfish) the cortical tissue forms a pair of bodies situated between the kidneys, known as the inter-renal bodies, whereas the chromaffin tissue is completely separate and forms segmentally arranged bodies closely related to the ganglia of the sympathetic trunk. In amphibia the chromaffin tissue borders on the cortical tissue but is not enclosed to form a medulla. Coupland† has shown that in the dogfish the chromaffin tissue produces only noradrenalin; in the frog it produces mainly noradrenalin, and small amounts of adrenalin; in the rabbit and man the chromaffin tissue of the suprarenal medulla produces mainly adrenalin and some noradrenalin, whereas the chromaffin cells of the para-aortic bodies, which are not closely associated with cortical tissue, produce noradrenalin only. It thus appears that the presence of cortical tissue in close proximity to the chromaffin tissue determines the appearance of adrenalin by the methylation of the primary amine, noradrenalin.

Vessels and Nerves.—The suprarenal gland is an exceedingly vascular organ. The arteries, which are of comparatively large size, are derived from the abdominal aorta, and the phrenic and renal arteries.

The *suprarenal vein* emerges from the hilus of the gland; that of the right gland opens into the inferior vena cava, that of the left into the left renal vein.

The *lymph* vessels end in the lateral aortic glands.

The *nerves* are exceedingly numerous. They are mainly medullated preganglionic sympathetic fibres and are described on p. 1217. They are distributed to the chromaffin cells in the medulla of the gland. The activities of the suprarenal cortex are largely controlled by adrenocorticotrophic hormone (A.C.T.H.) secreted by the anterior lobe of the hypophysis.

Applied Anatomy.—Various clinical conditions may occur as the result of lesions affecting the cortex or medulla of the suprarenal and they are attributable to the effects of excess or deficiency of the secretions of these parts of the gland.

Atrophy or tuberculosis of the suprarenal cortex, with consequent insufficiency of cortical secretion, results in Addison's disease, which is characterised by muscular weakness, low blood pressure, anaemia, brownish pigmentation of the skin, changes in electrolyte and fluid balance of the tissues, and terminal circulatory and renal failure. Excessive cortical secretion due to tumours or hyperplasia of the cortex may produce various effects. (1) In the adult, Cushing's syndrome may result, characterised by obesity, excessive hairiness of the face and trunk, diabetes mellitus, and impotence and hypogonadism in the male or amenorrhoea in the female. (2) In women, masculinisation of the secondary sex characters (virilism) may occur due to excessive secretion of androgenic hormones. (3) In men, feminisation, particularly breast enlargement, may occur. (4) In children, there may be precocious body growth and development of the external genital organs, with early menstruation in the female. (5) In the female foetus, hyperplasia of the cortex occurring between the third and fourth months gives rise to the condition of female pseudohermaphroditism, the excessive androgen secretion interfering with the differentiation of the urogenital sinus that occurs at this time, so that the urethra and vagina open into a persistent urogenital sinus; the clitoris also enlarges and the external genital organs thus resemble those of the male. In the male foetus, cortical hyperplasia at this time causes excessive development of the external genital organs.

Bilateral removal of the suprarenal glands (adrenalectomy) is used in the treatment of advanced, inoperable cases of disseminated cancer of the breast or prostate, which do not respond to X-ray therapy and where the malignant changes are dependent on hormonal control (androgens or oestrogens).

Of the 28 steroids that have been isolated from the cortex, one, called cortisone, inhibits the production of collagen fibres; it is used with benefit in the treatment of rheumatoid arthritis where a material called fibrinoid (which may be formed by the degeneration of collagen fibres) is deposited in the intercellular substance of the joint tissues. Cortisone also has an inhibitory effect on allergic phenomena (asthma, hay fever, serum sickness, etc.). Treatment with cortisone maintains life in Addison's disease and in cases where the suprarenals have been removed surgically.

Tumours of the suprarenal medulla and of the para-aortic bodies (phaeochromocytomas) may occur; they may be simple or malignant, and the consequent excessive secretion of adrenalin and noradrenalin produces attacks of palpitations, sweating, pallor of the skin, hypertension, headaches, and, if the tumours are of long-standing duration, retinitis and vascular changes in the kidneys.

* M. F. L. Keene and E. E. Hewer, *J. Anat., Lond.*, 1927, **61**, 302.

† R. E. Coupland, *J. Endocrinol.*, 1953, **9**, 194.

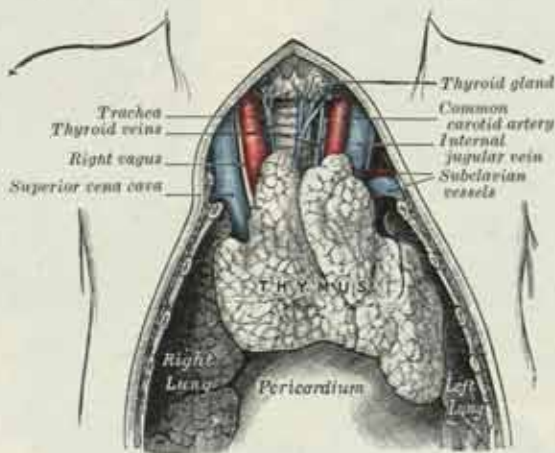
THE THYMUS

THE THYMUS (fig. 1271)

The **thymus** varies in size with age. At birth it commonly weighs between 10 and 15 gm.; it continues to grow up to the age of puberty, when its weight ranges between 30 and 40 gm. Thereafter it generally progressively diminishes in size, undergoing gradual atrophy and replacement by fat, so that after mid-adult life it may weigh only about 10 gm., though it may remain large and weigh between 28 and 50 gm.³

In early life it is pinkish-grey in colour, soft and finely lobulated on its surfaces, and consists of two unequally-sized, pyramidal lobes connected together by areolar tissue. Although the thymus is customarily described as a single unpaired organ, each lobe is developed from the third pharyngeal pouch of its own side (p. 184), and strictly there are two separate thymic bodies, right and left. The thymus lies

FIG. 1271.—The thymus of a full-time foetus. Exposed *in situ*.



in the anterior and superior mediastina of the thorax, extending as far inferiorly as the fourth costal cartilages, and its upper tapering parts extend into the neck, sometimes as far as the lower part of the thyroid gland, or even higher. Its shape is largely determined by the structures related to it and upon which it is moulded. Anteriorly, it is covered by the sternum and the Sternohyoid and Sternothyroid muscles. Posteriorly, it is moulded on the pericardium, the aortic arch and its branches, the left brachiocephalic vein, and the front and sides of the trachea. After mid-adult life it becomes yellowish in colour due to its gradual replacement by fat. Small accessory nodules of thymic tissue may occur in the neck as detached parts of the thymic diverticula in their developmental descent (p. 184), or the main thymus may be continued upwards as thin strands into the neck along this path, reaching to the thyroid cartilage or even slightly higher. Sometimes the cervical part of the thymus is represented by strands of connective tissue which connect the thymus to the inferior parathyroid glands. The nodules may be closely associated with the parathyroids, those related to the superior parathyroids (parathyroids IV) being developed from the fourth pharyngeal pouch.

Structure (fig. 1272A and B).—Each lobe is surrounded by a delicate fibrous capsule, from which septa penetrate for a short distance to divide the lobe into irregular lobules, each about 1 mm. to 2 mm. in diameter. The lobules are not completely separated from each other by these septa, and the deeper (medullary) parts of the lobules are continuous with each other in the central parts of the lobe. Each lobule consists of a cortical and medullary portion; the septa do not pass into the medullary

* M. Young and H. M. Turnbull, *J. Path. Bact.*, 1931, **34**, 213; G. Keynes, *Brit. Med. J.*, 1954, **ii**, 659.

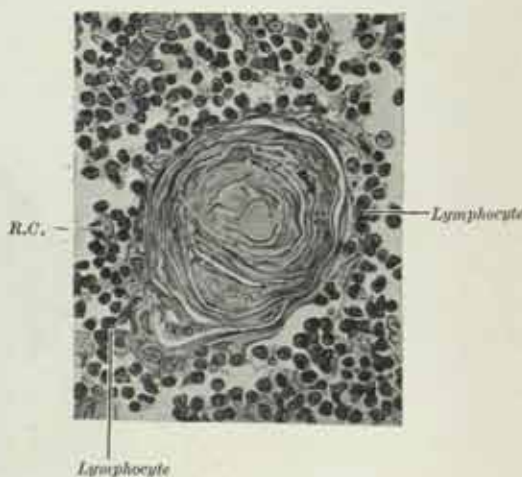
part. The *cortex* of each lobule is composed mainly of lymphocytes, supported by a network of branched reticular cells, though the presence of these is obscured by the heavy concentration of lymphocytes in the cortex. The *medulla* contains fewer lymphocytes than the cortex, so that here the presence of the reticular cells is more obvious in histological sections. The reticular cells are large, irregularly branched cells, with pale-staining nuclei, and they form a reticulum in the meshes of which lie the lymphocytes. The reticular cells are believed to be derived from the original entodermal pharyngeal thymic diverticula *; their epithelial nature is more obvious in fetal life, or after destruction of the lymphocytes by exposure of the thymus to X-rays. They differ from reticular connective tissue cells in that they do not take up

FIG. 1272A.—A section through the thymus of a new-born child, showing the general follicular structure. $\times 8$.



A

FIG. 1272B.—A concentric corpuscle. $\times 380$.



R.C., Reticular cell

B

injected vital dyes, like trypan blue. The medulla also contains nest-like bodies, called the *concentric corpuscles* (of Hassall), which are $30-100\mu$ in diameter. Each is composed of a central mass of hyaline material and broken-up nuclei, and it sometimes contains small cysts or deposits of calcium. Surrounding the central mass are a few layers of concentrically arranged flattened epithelial cells, the innermost ones of which may be dead and undergoing degeneration. As the thymus undergoes atrophy with increasing age, there is a gradual disappearance of the lymphocytes and their replacement by fat. The concentric corpuscles are the last elements to undergo involution, and in old age the thymus may consist of the corpuscles surrounded by a few reticular cells and lymphocytes and fat.

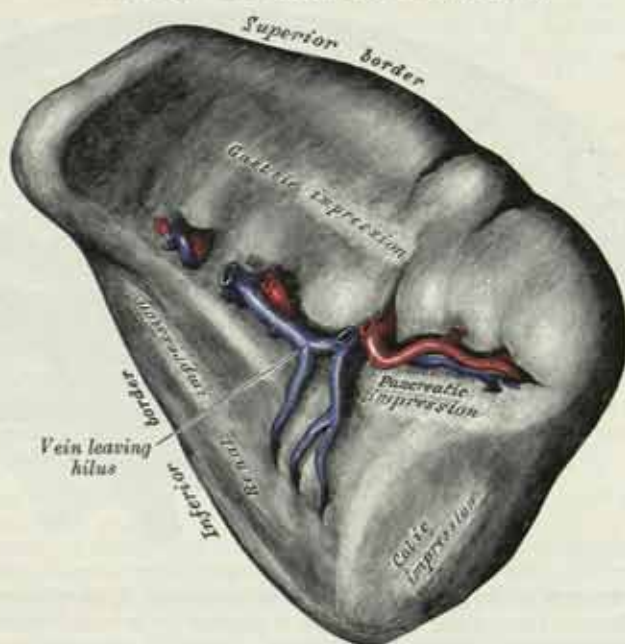
Vessels and Nerves.—The *arteries* are derived from the internal thoracic and inferior thyroid arteries. The *veins* end in the left brachiocephalic, internal thoracic and inferior thyroid veins; commonly one or more veins emerge from the medial side of each lobe and join together to form a common trunk which opens into the left brachiocephalic vein. The *lymph vessels* are described on p. 912. The *nerves* are small and are derived from the sympathetic (inferior cervical ganglion or ansa subclavia) and the vagus; branches from the phrenic and descendens cervicalis are distributed to the capsule of the thymus.

Applied Anatomy.—Apart from the production of lymphocytes, the functions of the thymus are doubtful, and it is not generally agreed that it produces a hormone. Castration or adrenalectomy delays involution of the thymus, whereas hypertrophy of the suprarenal cortex (or injection of cortisone) or the injection of androgenic hormones causes atrophy of the thymus. It is thus believed that normal involution is due to the androgenic hormones produced in the gonads at puberty. A persistently enlarged thymus may be associated with under-development of the external genital organs and of the secondary sex characters. The fact that the thymus is generally best developed before puberty has suggested that it may in some way be connected

* E. H. Norris, *Contrib. Embryol. Carneg. Instn.*, 1938, 27, 191.

with the general growth processes in the body. It has also been thought that the reticular cells may be the source of any hormone production that may occur in the thymus. In the past, the term 'status thymolympathicus' was used to denote a condition in which sudden death in young persons occurred after slight injury or during the administration of anaesthetics (especially chloroform). In some of these cases the thymus was found to be enlarged, with or without general enlargement of other lymphoid structures in the body, but such a condition is not now believed to constitute a clinical pathological entity* and these cases of sudden death are attributed to a subnormal general constitution of the individual, with inadequate circulatory mechanism and consequent heart failure under comparatively trivial circumstances. In young children, a large thymus (hyperplasia) may in rare cases press on the trachea and cause attacks of respiratory stridor, or noisy and difficult breathing. Tumours of the thymus may press on the trachea, the oesophagus, and the large veins at the root of the neck, causing hoarseness, cough, dysphagia and cyanosis. Myasthenia gravis is a chronic disease in adults characterised by diminution in the power of contraction of certain voluntary muscles after repetitive contractions have been carried out. The muscles most commonly involved are the Levator palpebrae superioris (leading to ptosis or drooping of the upper eyelid) and the orbital muscles (leading to diplopia or double vision). Other muscles (facial, masticatory, neck and limb muscles) may be involved, including in severe cases the respiratory muscles. In many of these cases some abnormality of the thymus has been observed, such as a general enlargement (hyperplasia) or a tumour (thymoma, composed of epithelial cells derived from the reticular cells or possibly from the lymphocytes), and in a number of these cases transient or more lasting improvement may follow removal of the thymus. The condition is believed to be due to a defect in neuromuscular transmission caused by the liberation in the thymus of some curare-like inhibitor substance

FIG. 1273.—The visceral surface of the spleen.



which blocks neuromuscular transmission, possibly by inhibiting the synthesis of acetylcholine at the nerve endings. The condition is alleviated by injection of prostigmine (neostigmine) which is known to antagonise the action of curare, and it has been shown† that extracts from the thymus removed from patients with myasthenia gravis, or even from the apparently normal thymus of fetuses and infants, depress contractions in experimental muscle-nerve preparations. For this reason it is thought that the normal thymus exerts some sort of control over the neuromuscular transmission mechanism.

* M. Young and H. M. Turnbull, *J. Path. Bact.*, 1931, **34**, 213.

† A. Wilson, A. R. Obrist and H. Wilson, *Lancet*, 1953, **ii**, 368.

THE SPLEEN (LIEN) (figs. 1273 to 1277)

The **spleen** is situated principally in the left hypochondriac region of the abdomen, but its posterior end extends into the epigastric region; it lies between the fundus of the stomach and the Diaphragm. It varies in shape, according to the size of the colic impression, from that of a slightly curved wedge (if the colic impression is small) to a tetrahedron (if the colic impression is large). Its long axis lies in the line of the tenth rib, its posterior extremity being about 3.5 to 4.0 cm. from the mid-dorsal line opposite the spine of the tenth thoracic vertebra, and its anterior extremity reaching as far as the mid-axillary line. It is soft, of very friable consistence, highly vascular, and of a dark purplish colour.

Relations.—The *diaphragmatic surface* is convex, smooth and faces upwards, backwards, and to the left, except at its posterior end, where it faces slightly medially. It is in relation with the abdominal surface of the Diaphragm, which separates it from the lowest parts of the left lung and pleura and the ninth, tenth and eleventh ribs of the left side. The costodiaphragmatic recess of the pleura extends down as far as the inferior border of the spleen.

The *visceral surface* (fig. 1273) is directed towards the abdominal cavity, and presents gastric, renal, pancreatic and colic impressions.

The *gastric impression*, directed forwards, upwards, and medially, is broad and concave. It is in contact with the posterior wall of the stomach, from which it is

FIG. 1274.—A transverse section through the spleen, showing the trabecular tissue and the splenic vein and its tributaries.



separated by a recess of the greater sac of the peritoneum. It presents near its lower limit a long fissure, termed the *hilus*. This is pierced by several irregular apertures for the entrance and exit of vessels and nerves.

The *renal impression*, which is very gently concave, is placed on the lower part of the visceral surface and is separated from the gastric impression above by a raised margin. It is directed medially, downwards and a little backwards, and is related to the upper and lateral part of the anterior surface of the left kidney and, sometimes, to the upper pole of the left suprarenal gland.

The *colic impression* is placed at the lateral extremity of the spleen and is usually flattened. It is related to the left colic flexure and phrenicocolic ligament (p. 1410).

The *pancreatic impression*, when present, is small and is placed between the colic impression and the lateral part of the hilus. It is directly related to the tail of the pancreas which lies in the lienorenal ligament.

The *superior border* separates the diaphragmatic surface from the gastric

impression. It is usually convex upwards and is marked, near its lateral end, by one or two notches of variable depth. The notches indicate the lobulated character of the spleen in early fetal life (p. 199). The *inferior border* separates the renal impression from the diaphragmatic surface and lies between the Diaphragm and the upper part of the lateral border of the left kidney. It is blunter and more rounded than the superior border and corresponds to the lower margin of the eleventh rib.

The *posterior extremity* of the spleen is blunt and rounded in most cases. It is directed towards the vertebral column. The *anterior extremity* is more expanded, and commonly takes the form of a margin connecting the lateral ends of the upper and lower borders. It is related to the left colic flexure and to the phrenicocolic ligament. •

The spleen is almost entirely surrounded by peritoneum, which is firmly adherent to its capsule. Recesses of the greater sac intervene between the spleen and the stomach, and between the spleen and the left kidney. It develops in the upper part of the dorsal mesogastrium (p. 199) and remains connected with the stomach and the posterior abdominal wall by two folds of peritoneum. One, termed the *lienorenal ligament*, is derived from the peritoneum where the wall of the general peritoneal cavity comes into contact with the omental bursa between the left kidney and spleen; the splenic vessels pass between its two layers (fig. 1168). The other fold, termed the *gastrosplenic ligament*, also consists of two layers, and is formed by the meeting of the walls of the greater sac and omental bursa between the spleen and stomach (fig. 1168); the short gastric and left gastro-epiploic branches of the splenic artery run between its two layers. The lateral part of the lateral end of the spleen is in contact with the phrenicocolic ligament.

The size and weight of the spleen vary at different periods of life, in different individuals, and in the same individual under different conditions. In the adult it is usually about 12 cm. in length, 7 cm. in breadth, and 3 or 4 cm. in thickness, but it tends to diminish in size and weight with advancing age. Its average weight in the adult is about 150 gm., though it may range between 80 and 300 gm., largely according to the amount of blood it contains.

The size of the spleen slowly increases during digestion, and varies according to the state of nutrition of the body, being large in highly fed, and small in starved, animals.

Frequently in the neighbourhood of the spleen, and especially in the gastrosplenic ligament and greater omentum, small encapsulated nodules of splenic tissue may be found, either isolated or connected to the spleen by thin bands of splenic tissue. They are known as *accessory spleens* and they may be very numerous and widely scattered in the abdomen. The spleen may retain its fetal lobulated form, or there may be deep notches on the diaphragmatic surface and inferior border, in addition to those usually present on the superior border.

Surface Anatomy.—The position of the spleen in the living can be determined by percussion. The dull area extends over the ninth, tenth and eleventh ribs in vertical extent and should not extend forwards further than the mid-axillary line. The normal spleen is not palpable.

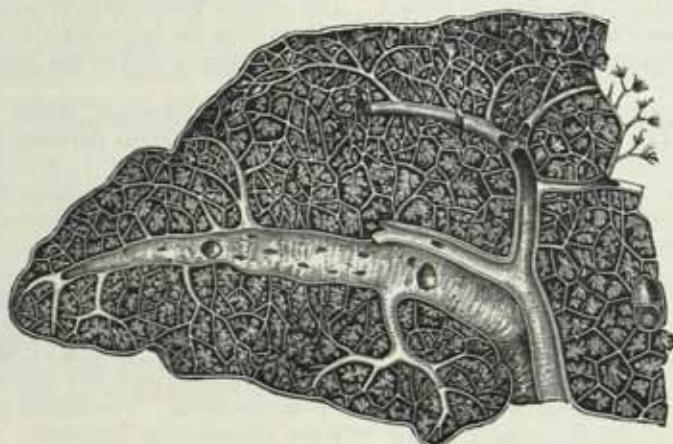
Structure.—The spleen is invested by two coats: an external serous and an internal fibro-elastic coat.

The *external, or serous, coat* is formed by the peritoneum; it is thin, smooth, and in the human subject intimately adherent to the fibro-elastic coat. It invests the entire organ, except at the hilus and along the lines of reflection of the lienorenal and gastrosplenic ligaments.

The *fibro-elastic coat, or capsule*, invests the organ and from it *trabeculae* pass into the spleen and branch to form a network which constitutes the framework of the spleen (fig. 1274). The largest trabeculae pass in from the hilus and ensheath the splenic vessels, which divide into branches that run in the subdivisions of the trabeculae (fig. 1275). The capsule and trabeculae consist of collagenous white fibrous tissue and yellow elastic fibres, the latter being more numerous in the trabeculae. In many mammals the capsule and trabeculae contain numerous plain muscle fibres and the rhythmical contraction of the spleen is attributed to these fibres. In man, very few muscle fibres are present in the capsule and trabeculae, and contraction and distension of the spleen are attributed to constriction or relaxation of the blood vessels (*see below*) with consequent alteration in the amount of blood in the organ. Increase in the blood content distends the spleen and stretches the elastic fibres in the capsule and trabeculae; contraction of the spleen is due to the recoil of these fibres.

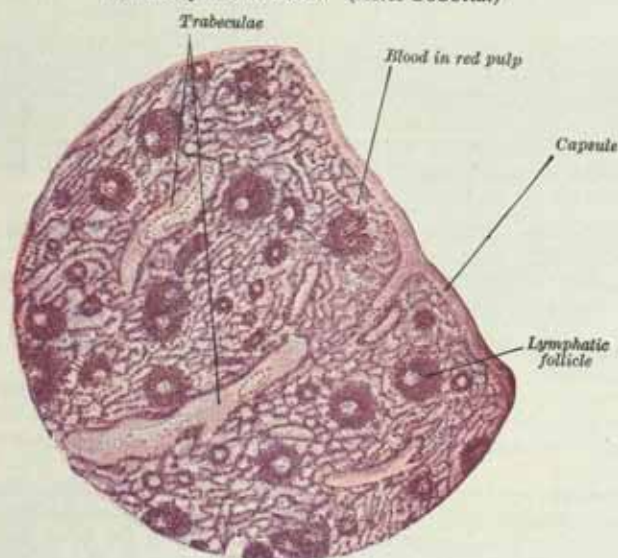
The subdivisions of the trabeculae are continuous with a meshwork of fine reticular fibres, in the interstices of which the *splenic pulp* is contained. There are two kinds of splenic pulp, the red pulp and the white pulp, which are both related to the blood-vessels permeating the spleen.

FIG. 1275.—A transverse section through the human spleen, showing the distribution of the splenic artery and its branches.



Circulation of blood inside the spleen.*—The large, tortuous splenic artery, before it reaches the spleen, divides in the lienorenal ligament into five or more branches which enter the hilus of the organ and ramify throughout its substance in the trabeculae. The splenic vein is formed in the lienorenal ligament by the junction of five or more tributaries which emerge from the hilus. Small arteriolar branches

FIG. 1276.—A section through a portion of the human spleen. $\times 515$. Stained with hæmatoxylin and eosin. (After Sobotta.)

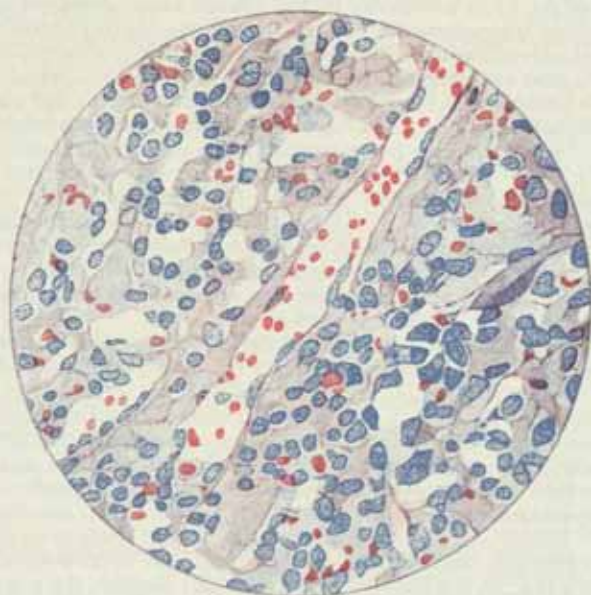


of the splenic arteries leave the trabeculae, and their adventitial coat becomes replaced by a sheath of lymphatic tissue which accompanies the vessels and their branches almost as far as their division into capillaries. These lymphatic sheaths constitute the *white pulp* of the spleen, and here and there the sheaths are enlarged to form the

* M. H. Knisely, *Anat. Rec.*, 1936, **65**, 23 and 131; D. W. MacKenzie, A. O. Whipple and M. P. Wintersteiner, *Amer. J. Anat.*, 1941, **68**, 397; T. Snook, *Amer. J. Anat.*, 1950, **87**, 31; H. M. Peck and N. L. Hoerr, *Anat. Rec.*, 1951, **109**, 447; O. J. Lewis, *J. Anat., Lond.*, 1957, **91**, 245.

splenic lymphatic follicles (Malpighian bodies), which vary in diameter from 0.25 mm. to 1 mm. and are visible to the naked eye on the freshly cut surface of the organ as whitish semi-opaque dots contrasting with the dark red colour of the surrounding tissue, which constitutes the *red pulp* of the spleen. These lymphatic or lymphoid follicles are centres of lymphocyte production. There are no lymph vessels in the follicles and the lymphocytes migrate by amoeboid movement into the surrounding red pulp and continue to multiply there. The follicles atrophy with increasing age and may be absent in old age. The arterioles usually occupy an eccentric position in the follicles and give off fine side branches to supply the follicles. The arterioles finally lose their sheaths of lymphatic tissue and enter the surrounding red pulp, where they at once divide into a number of straight vessels termed *penicilli*. Each of these straight vessels, after running a course of about 0.5 mm., shows a slight thickening of its coat, known as an *ellipsoid*, which is formed by a condensation of reticular cells and macrophages, and the lumen of the vessel is considerably narrowed. The

FIG. 1277.—A thin section of the splenic pulp of a young subject, showing one of the splenic venules on longitudinal section. Many fragments of disintegrated red blood-corpuscles can be seen within the phagocytic splenic cells. Stained with hæmatoxylin and eosin. $\times 350$.



ellipsoids are well developed in some mammals but are only feebly developed in man. Beyond the ellipsoids, each vessel continues as an arterial capillary, or may divide into two capillaries, the termination of which is undecided. According to the 'closed' theory of the splenic circulation, the capillaries are directly continuous with venous sinusoids that lie in the red pulp, and these in their turn convey the blood to the venous tributaries of the splenic veins that lie in the trabeculae and eventually emerge from the organ at the hilus, the endothelial coat of the capillaries, sinusoids and veins being continuous so that the blood does not come into direct contact with extravascular structures. According to the 'open' theory of the splenic circulation, the capillaries end by opening directly into the red pulp, so that the blood lies in the interstices of the reticular tissue. The venous sinusoids are lined by long narrow cells arranged in the long axis of each sinus, outside which are circularly arranged reticular fibres, and between the lining cells it is claimed that there are numerous permanent openings in the walls of the sinusoids through which the blood can pass back from the red pulp into the sinusoids and thence to the veins. Some adopt a 'compromise' theory and claim that, whereas the circulation may be 'open' in the distended spleen, it becomes functionally 'closed' in the contracted organ, while others maintain that the lining cells of the sinusoids are extremely sensitive and that even with a 'closed' circulation they may become permeable to red blood cells in various circumstances. The above theories are bound up with the question of the mechanism of storage of erythrocytes in the spleen.

Red pulp contains numerous erythrocytes, phagocytic reticulo-endothelial cells (macrophages), lymphocytes (derived from the lymphatic follicles) and monocytes

(formed from lymphocytes). Worn out erythrocytes are ingested by the macrophages, the hæmoglobin being converted into bilirubin and the iron-containing moiety of hæmoglobin; the former is conveyed to the liver whereas the latter is conserved and conveyed to the red bone marrow to be utilised in the formation of new erythrocytes; the macrophages in the spleen contain brownish granules of hæmosiderin. The spleen at times stores erythrocytes, the storage mechanism involving the separation of erythrocytes from plasma, but the site of separation and storage is uncertain; according to the 'closed' theory of splenic circulation it is in the venous sinusoids, the filling and emptying of which are controlled by sphincters at each end of the sinusoids, whereas according to the 'open' theory it is in the reticular meshes of the red pulp. In states of emergency, especially those associated with anoxia, the erythrocytes are discharged into the circulation, thus increasing the oxygen carrying capacity of the blood. In most mammals, the discharge is due to contraction of the plain muscle in the capsule and trabeculae under the influence of the sympathetic nervous system and adrenalin; in man it is due to recoil of the stretched elastic fibres of the distended spleen, though the blood storage and discharge function of the human spleen is not nearly so marked as in other species.

There is evidence* (See J. L. Braithwaite and D. J. Adams, *J. Anat., Lond.*, 1957, **91** 352) that the spleen in man and other animals consists of separate 'segments' or 'compartments', each supplied by one of the hilar branches of the splenic artery and drained by one of the hilar tributaries of the splenic vein. Adjacent compartments are connected by an intersegmental vein so that if one compartment becomes congested with blood, excess blood could pass by these channels to adjacent compartments.

The spleen is also concerned in the formation of antibodies, which are probably produced by the plasma cells (derived from lymphocytes) in the red pulp. Extirpation of the spleen in animals or of the traumatically ruptured (but otherwise normal) spleen in man indicates that it is not essential for the ordinary maintenance of health and life. In the human foetus, from the fourth month onwards, the spleen is an important hæmatopoietic organ and the red pulp contains groups of myelocytes, erythroblasts and megakaryocytes. In some anæmias and myeloid leukemia in post-natal life, the reticulo-endothelial cells in the red pulp may undergo a 'myeloid metaplasia' and revert to a hæmatopoietic function.

The *lymph vessels* of the spleen are few and are confined to the capsule and the thickest trabeculae. They are described on p. 901.

The *nerves* are derived from the celiac plexus and are chiefly non-medullated. In man their distribution is confined mainly to the branches of the splenic arteries; in other mammals they also supply the plain muscle in the capsule and trabeculae.

Applied Anatomy.—The spleen may become enlarged in many infections, notably in malaria, where it may weigh as much as 9 kilos. In splenic enlargement it is the anterior extremity, the anterior part of the diaphragmatic surface and the notched superior border that become palpable below the left costal margin; the notches become exaggerated and may be easily palpable. The left part of the transverse colon and the left colic flexure are displaced downwards, so that there is no area of colonic resonance on percussion over the enlarged organ; this is in contrast to a retro-peritoneal tumour (e.g. of the kidney) which does not displace the gut and in which therefore an area of colonic resonance can be elicited on percussion over the palpable tumour. There is no anastomosis between the smaller branches of the splenic arteries, so that obstruction leads to infarction of the spleen. In surgical removal of the spleen, damage to the tail of the pancreas must be avoided when ligaturing the splenic vessels near the hilus.

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